91-4015

DOE/ID-22094

Background Concentrations of Selected Radionuclides, Organic Compounds, and Chemical Constituents in Ground Water in the Vicinity of the Idaho National Engineering Laboratory

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 91-4015

Prepared in cooperation with the U.S. Department of Energy

I 19.42/4:

READEX FICHE best copy available

ERRATA

Page v, last paragraph; should include abbreviated unit "mrem/yr (millirem per year)".

Page 1, third paragraph; "both range are" should read "both range from".

Page 37, first paragraph, last sentence; "upgradikllHent" should read "upgradient and downgradient".

Cover: *From left, East Butte, Middle Butte, and Big Southern Butte, Idaho National Engineering Laboratory.*

Photograph courtesy of T. D. Reynolds, U.S. Department of Energy, Environmental Sciences Branch

BACKGROUND CONCENTRATIONS OF SELECTED RADIONUCLIDES, ORGANIC COMPOUNDS, AND CHEMICAL CONSTITUENTS IN GROUND WATER IN THE VICINITY OF THE IDAHO NATIONAL ENGINEERING LABORATORY

By Brennon R. Orr, L. DeWayne Cecil, and LeRoy L. Knobel

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 91-4015

Prepared in cooperation with the

U.S. DEPARTMENT OF ENERGY

Idaho Falls, Idaho

February 1991

U.S. DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
INEL, MS 4148
P.O. Box 2230
Idaho Falls, ID 83403-2230

Copies of this report can be purchased from:

U.S. Geological Survey
Books and Open-File Reports Section
Box 25425, Federal Center
Denver, CO 80225

CONTENTS

	Page
Abstract	1
Introduction	2
Purpose and scope	3
Hydrologic setting	4
Guidelines for the interpretation of data	5
Background concentrations of selected radionuclides	6
Uranium and thorium decay series	10
Total uranium	10
Radium	10
Radon	12
Transuranic elements	16
Tritium	17
Strontium-90	19
Iodine-129	22
Gross measurements of radioactivity	23
Gross alpha-particle radioactivity	23
Gross beta-particle radioactivity	26
Gamma-ray spectrometry	26
Cesium-137	28
Cobalt-60	28
Potassium-40	28
Background concentrations of selected organic compounds and inorganic chemical constituents	31
Selected organic compounds	31
Purgeable organic compounds	33
Pesticides	36
Selected inorganic constituents	37
Arsenic	38
Barium	39
Cadmium	40
Chromium	41
Lead	41
Mercury	42
Selenium	43
Silver	44
Fluoride	45
Nitrate	46
Summary	46
Selected references	50

ILLUSTRATIONS

Page

Figure 1. Map showing location of the Idaho National Engineering Laboratory. 2
2. Chart showing the uranium-238 decay series. 7
3. Chart showing the thorium-232 decay series. 8
4. Chart showing the uranium-235 decay series. 9

Figures 5-17 Graphs showing:

5. The distribution of total uranium concentrations in water samples in Idaho. 11
6. The distribution of radium-226 and radium-228 concentrations in water samples from 12 wells and 3 irrigation wastewater drains 65 miles southwest of the Idaho National Engineering Laboratory 13
7. The distribution of radon-222 concentrations in water samples in Idaho. 14
8. The distribution of plutonium-238, plutonium-239, -240 (undivided), and americium-241 concentrations in water samples at the Idaho National Engineering Laboratory. . . 18
9. The distribution of tritium concentrations in water samples in Idaho. 20
10. The distribution of strontium-90 concentrations in water samples in Idaho. 21
11. The distribution of iodine-129 concentrations in water samples at the Idaho National Engineering Laboratory. . . 24
12. The distribution of gross alpha-particle concentrations in water samples in Idaho 25
13. The distribution of gross beta-particle concentrations in water samples in Idaho 27
14. The distribution of cesium-137 concentrations in water samples at the Idaho National Engineering Laboratory. . . 29
15. The distribution of cobalt-60 concentrations in water samples at the Idaho National Engineering Laboratory. . . 30
16. The distribution of potassium-40 concentrations in water samples at the Idaho National Engineering Laboratory. . . 32
17. The distribution of nitrate concentrations in water samples from the Snake River Plain aquifer. 34

TABLES

Table 1. Organic compounds for which maximum contaminant levels have been established 33
2. Inorganic constituents for which maximum contaminant levels have been established. 38

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per day (ft/day)	0.3048	meter per day
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per year (acre-ft/year)	1,233	cubic meter per year
foot per mile (ft/mi)	0.1646	meter per kilometer
ton	0.9072	megagram
curie (Ci)	3.7×10^{10}	becquerel
picocurie (pCi)	0.037	becquerel
picocurie per liter (pCi/L)	37.00	becquerel per liter

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units used in report: g (gram), g/ton (gram per ton), Ci/g (curie per gram), µg/L (microgram per liter), and mg/L (milligram per liter).

BACKGROUND CONCENTRATIONS OF SELECTED RADIONUCLIDES, ORGANIC COMPOUNDS, AND CHEMICAL CONSTITUENTS IN GROUND WATER IN THE VICINITY OF THE IDAHO NATIONAL ENGINEERING LABORATORY

By

Brennon R. Orr, L. DeWayne Cecil, and LeRoy L. Knobel

ABSTRACT

Background concentrations of radionuclides, organic compounds, and inorganic chemical constituents in water in the Snake River Plain aquifer were estimated from ground-water sample analyses. Detectable concentrations of transuranic elements should not be present in water from the Snake River Plain aquifer. Background concentrations of tritium generally range from 75 to 150 pCi/L (picocuries per liter). Strontium-90 and iodine-129 concentrations generally are 0 and from 0 to 0.05 pCi/L, respectively. At the INEL (Idaho National Engineering Laboratory), comparison of the mean and median concentrations of tritium, strontium-90, and iodine-129 indicates that operations locally have affected concentrations in ground water.

Gross alpha-particle and beta-particle radioactivity in water from the Snake River Plain aquifer range from 0 to 5 pCi/L and 0 to 8 pCi/L, respectively. Background gamma radiation in ground water is attributed to cesium-137, cobalt-60, and potassium-40. Ground water at the INEL generally contains no cesium-137 or cobalt-60. Naturally occurring concentrations of potassium-40 probably are about 300 pCi/L.

Background concentrations of organic compounds in water from the Snake River Plain aquifer generally are less than 0.2 µg/L (micrograms per liter). Background arsenic and chromium concentrations both range are 2 to 3 µg/L. Barium concentrations range from about 50 to about 70 µg/L. Lead and mercury concentrations generally are less than 5 µg/L and 0.1 µg/L, respectively. Cadmium, selenium, and silver concentrations generally are less

than 1 μg/L. Nitrate concentrations range from 0 to about 1.4 mg/L (milligrams per liter).

INTRODUCTION

The INEL (Idaho National Engineering Laboratory), a U.S. Department of Energy facility, was established in 1949 for research in peacetime uses of nuclear energy, development of nuclear safety-practices, national defense, and experimentation in alternative energy sources (fig. 1). Facilities at the INEL have generated radionuclide and chemical wastes that have been disposed to the subsurface through unlined infiltration ponds and disposal wells.

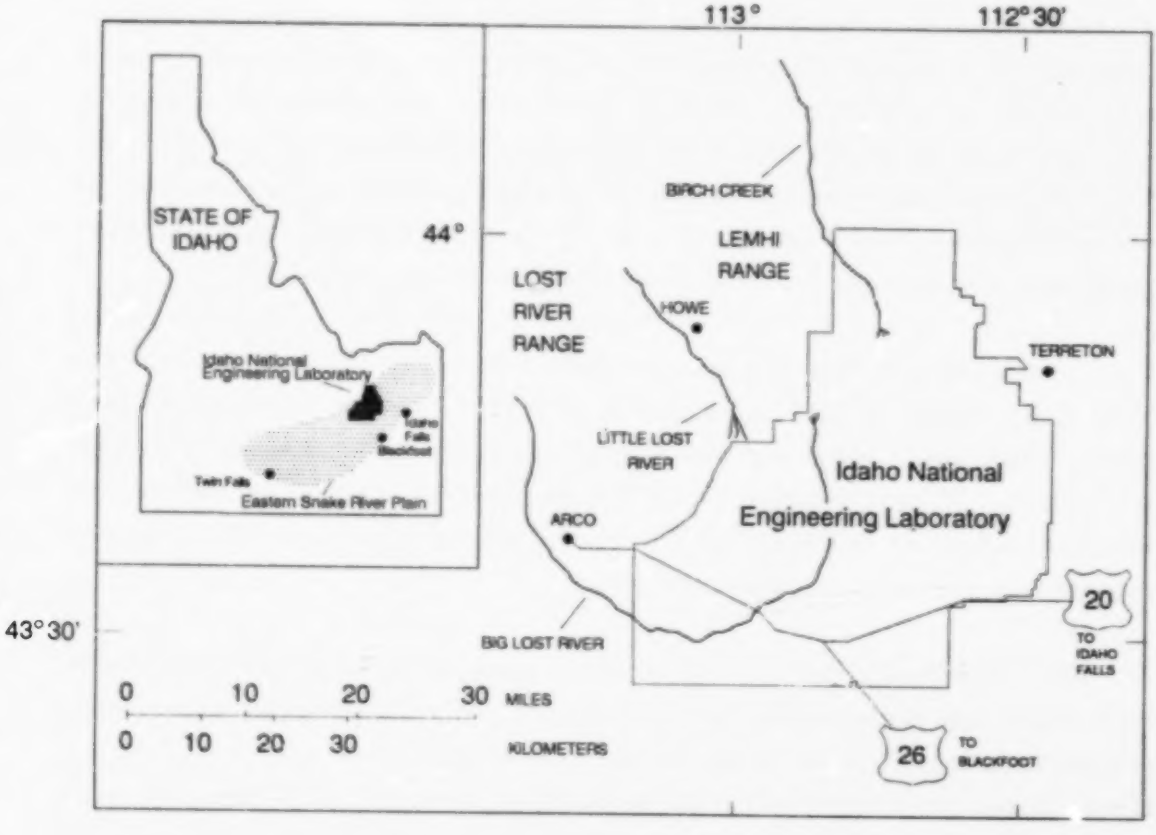

Figure 1.--Location of the Idaho National Engineering Laboratory

The U.S. Department of Energy, in accordance with requirements of the Resource Conservation and Recovery Act and the Comprehensive Environmental Response Compensation and Liability Act, is preparing a background characterization of ground water and soils at the INEL. In part, this characterization requires information concerning estimated background concentrations of selected radionuclides and chemical constituents in ground water and surface water. To obtain such information this study was done by the U.S. Geological Survey in cooperation with the U.S. Department of Energy at the request of the Idaho Department of Health and Welfare.

Purpose and Scope

This report documents background concentrations of selected radionuclides and chemical constituents in ground water in the vicinity of the INEL. These constituents include both naturally occurring and anthropogenic constituents originating from nuclear weapons tests and other widespread sources.

Background concentrations of constituents were compiled from chemical analyses of ground-water samples collected from wells at the INEL, in the Snake River Plain, and throughout the State of Idaho. Analyses of water samples from wells and irrigation wastewater drains 65 mi southwest of the INEL (Mann and Knobel, 1990) were used in this compilation. The distance between these sites and the INEL and estimated rates of ground-water flow preclude influence on water quality from operations at the INEL. The range, mean, and median of concentrations for respective constituents provided an indication of the distribution of these constituents in water. Data for local streams also were included to document background concentrations of these constituents in water entering the aquifer as recharge. Radionuclide and chemical data sets used in this report were selected because of their geographical distribution and because results were obtained using recent analytical methods and sensitive instrumentation.

Hydrologic Setting

The Snake River Plain is a structural basin encompassing approximately 15,000 mi^2 of the southern third of Idaho. The INEL is in the northern part of the eastern Snake River Plain. Saturated basaltic rocks and sedimentary interbeds with a combined maximum thickness of about 3,000 ft form the Snake River Plain aquifer, the most productive aquifer in the State.

Streamflow onto the Snake River Plain and related underflow from alluvial valleys in bordering mountain ranges recharge the Snake River Plain aquifer. Streams providing recharge near the INEL include the Big Lost River, Little Lost River, and Birch Creek. Most of the flow in these streams infiltrates through the stream channels, water-spreading areas, and playas to locally recharge the Snake River Plain aquifer. The average discharge of the Big Lost River near Arco for the 35-year period of record (1947-61, 1967-80, 1983-88) was 84,000 acre-ft/yr, and the average discharge of the Little Lost River near Howe for the 44-year period of record (1941-81, 1986-88) was 55,860 acre-ft/yr (Harenberg and others, 1988, p. 229, 234).

Water flows through fractures and intergranular pore spaces in the aquifer. The generalized direction of ground-water flow at the INEL is to the southwest at velocities ranging from 5 to 20 ft/d (Pittman and others, 1988, p. 11). The altitude of water levels in wells ranges from about 4,580 ft above sea level in the northern part of the INEL to about 4,430 ft above sea level in the southern part. The depth to water ranges from about 200 ft below land surface in the northern part to more than 900 ft below land surface in the southwestern part.

Discharge from the Snake River Plain aquifer occurs at large springs along the Snake River approximately 90 mi southwest of the INEL. Estimated discharge of these springs in 1988 was about 4.3 million acre-ft (Mann, 1989, p. 2).

Guidelines for the Interpretation of Data

Data for background concentrations of selected constituents in water are presented as a minimum and maximum concentration with a calculated mean and median concentration. The mean concentration generally describes a normally distributed data set and the median concentration describes a log-normally distributed data set (Horton, 1985, p. 12). The median concentration is useful in the interpretation of environmental radioactivity measurements because these data can be log-normally distributed (Gilbert and Kinnison, 1981, p. 378). The mean, median, minimum, and maximum concentrations are given for every constituent presented in this report. Frequency distribution graphs for selected constituents also are presented.

Data presented in this report are compiled from other studies. These data may or may not represent true background concentrations for the selected constituents in water in the vicinity of the INEL. Thus caution should be used in interpreting mean and median concentrations because water-sample collection methods, field-preservation techniques, and reference isotopes used for gross measurements of radioactivity may differ among studies and because the data may not be normally or log-normally distributed.

Many analytical results for environmental radioactivity measurements are at or near zero. If the true background concentration for a given radionuclide is zero, a given set of analytical results for that radionuclide should be distributed about zero, with negative and positive measurements. Negative analytical results occur if the radioactivity of a water sample is less than the background radioactivity or the radioactivity of the prepared blank sample in the laboratory.

The analytical results for radionuclides are presented with calculated analytical uncertainties. There is about a 67-percent probability that the true radionuclide concentration is in a range of the reported concentration plus or minus the uncertainty. The associated uncertainties presented with mean concentrations are calculated experimental standard errors and are an estimate of the uncertainty of the mean concentration (Iman and Conover,

1983, p. 158). The results for the organic and inorganic constituents are reported by the laboratories without associated analytical uncertainties.

BACKGROUND CONCENTRATIONS OF SELECTED RADIONUCLIDES

Natural concentrations of radioactivity must be determined to interpret ground- and surface-water quality data in the vicinity of the INEL. Those natural radionuclides occurring singly for which data are available in the vicinity of the INEL are ^{3}H (tritium) and ^{40}K (potassium-40). In addition, data are available for select members of three naturally occurring decay series: (1) the uranium series that has ^{238}U (uranium-238) as the initial member (fig. 2), (2) the thorium series that has ^{232}Th (thorium-232) as the initial member (fig. 3), and (3) the actinium series that originates with ^{235}U (uranium-235) (fig. 4). Data for three naturally occurring isotopes of uranium--^{238}U, ^{235}U, ^{234}U--are presented as total uranium. Data are presented for ^{226}Ra (radium-226) and ^{222}Rn (radon-222) from the uranium series and for ^{228}Ra (radium-228) from the thorium series.

Data also are presented for concentrations of several artificially produced transuranic elements, including ^{238}Pu (plutonium-238), ^{239}Pu-^{240}Pu (undivided) (the sum of concentrations of plutonium-239 and plutonium-240), and ^{241}Am (americium-241), and of selected radionuclides, including ^{137}Cs (cesium-137), ^{90}Sr (strontium-90), ^{129}I (iodine-129), and ^{60}Co (cobalt-60). Because all of these radionuclides are alpha-particle, beta-particle, and/or gamma-ray emitters, gross measurements of these types of radioactivity also are presented. Several of the radionuclides have maximum contaminant levels established by the U.S. Environmental Protection Agency (1989, p. 547-548, 608). In this report, the median radionuclide concentration is used to define the estimated upper limit of the range of background radionuclide concentrations in water from the Snake River Plain aquifer. The estimated lower limit generally is reported as zero.

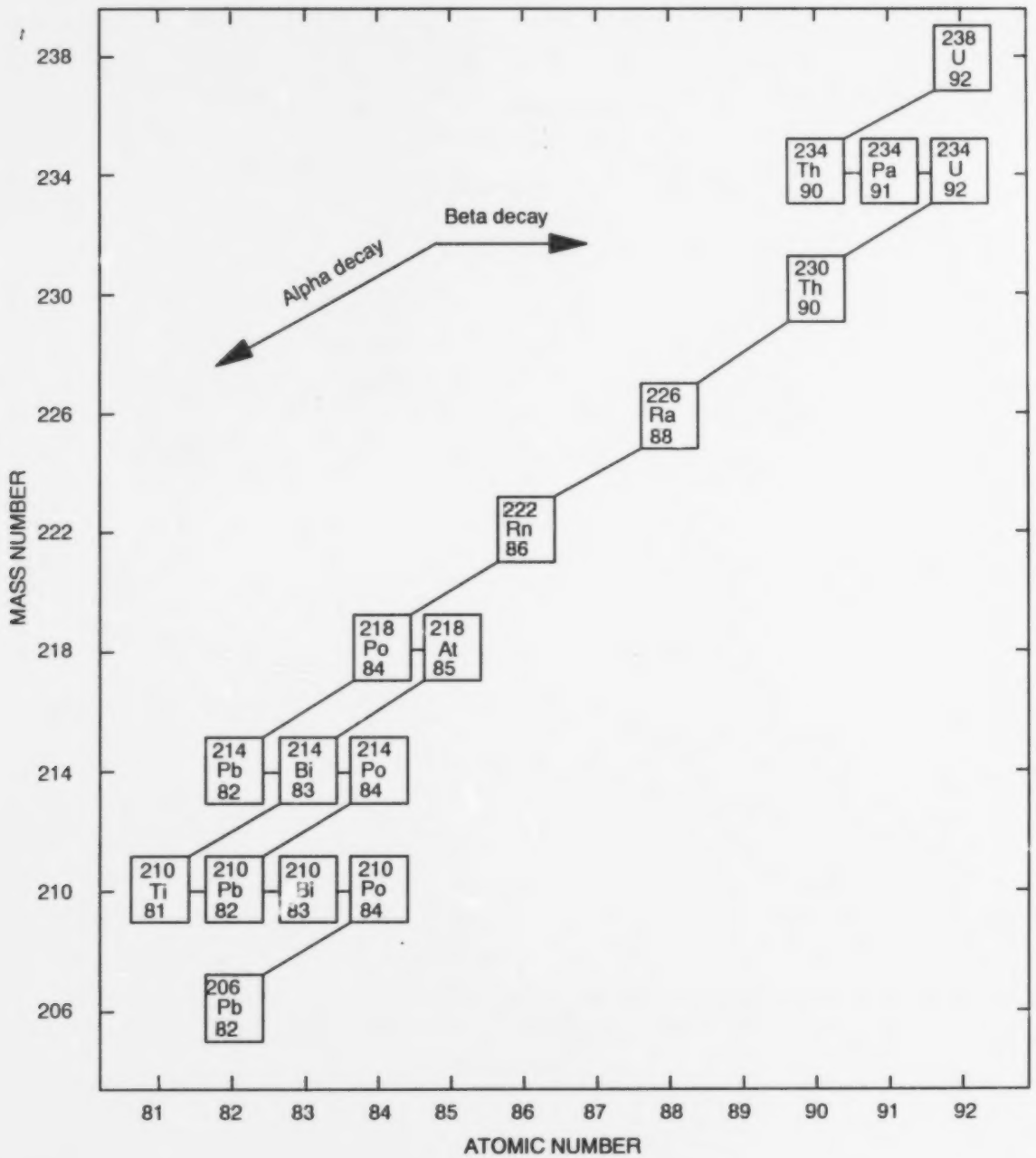

Figure 2.--The uranium-238 decay series.

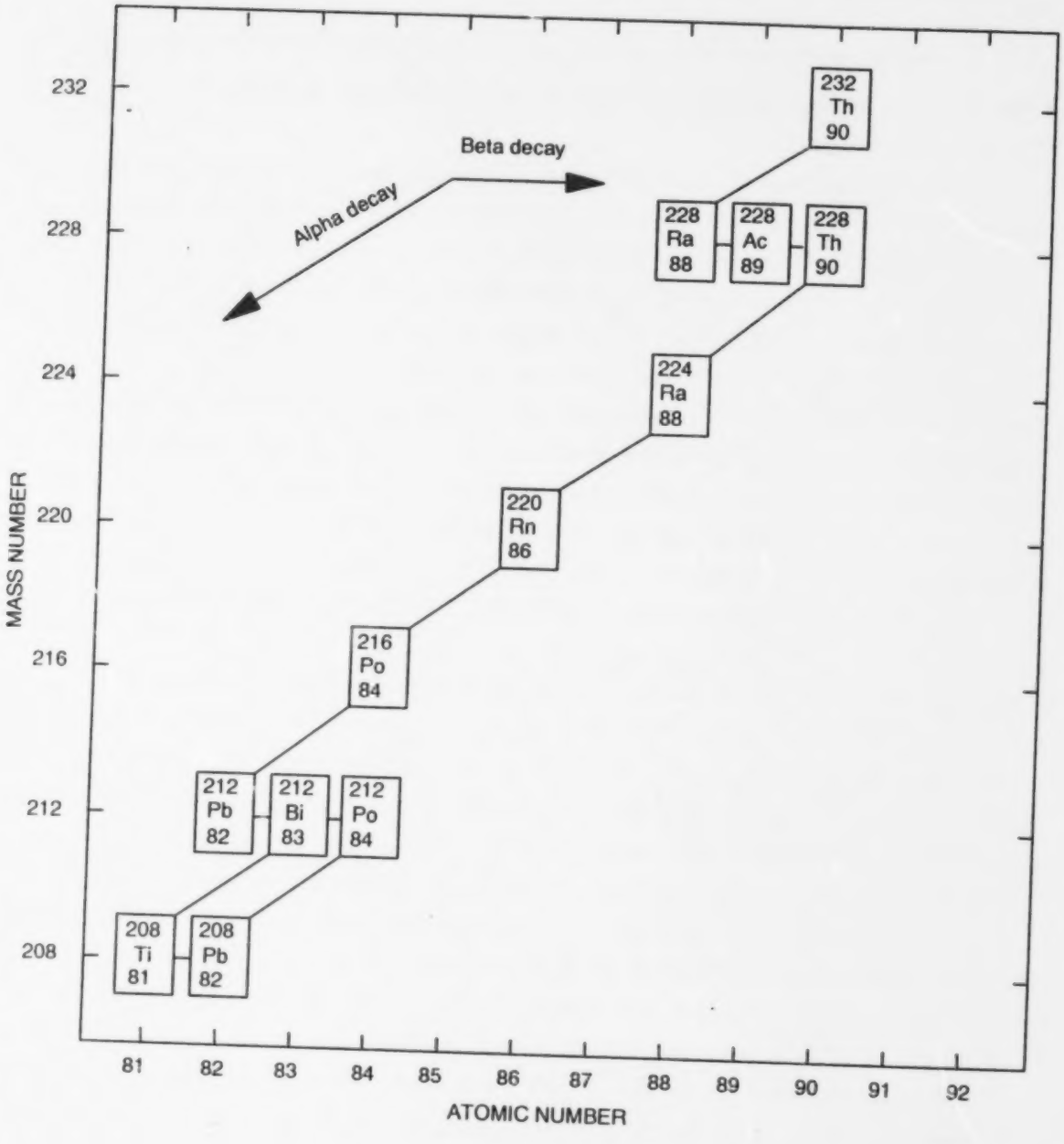

Figure 3.--The thorium-232 decay series.

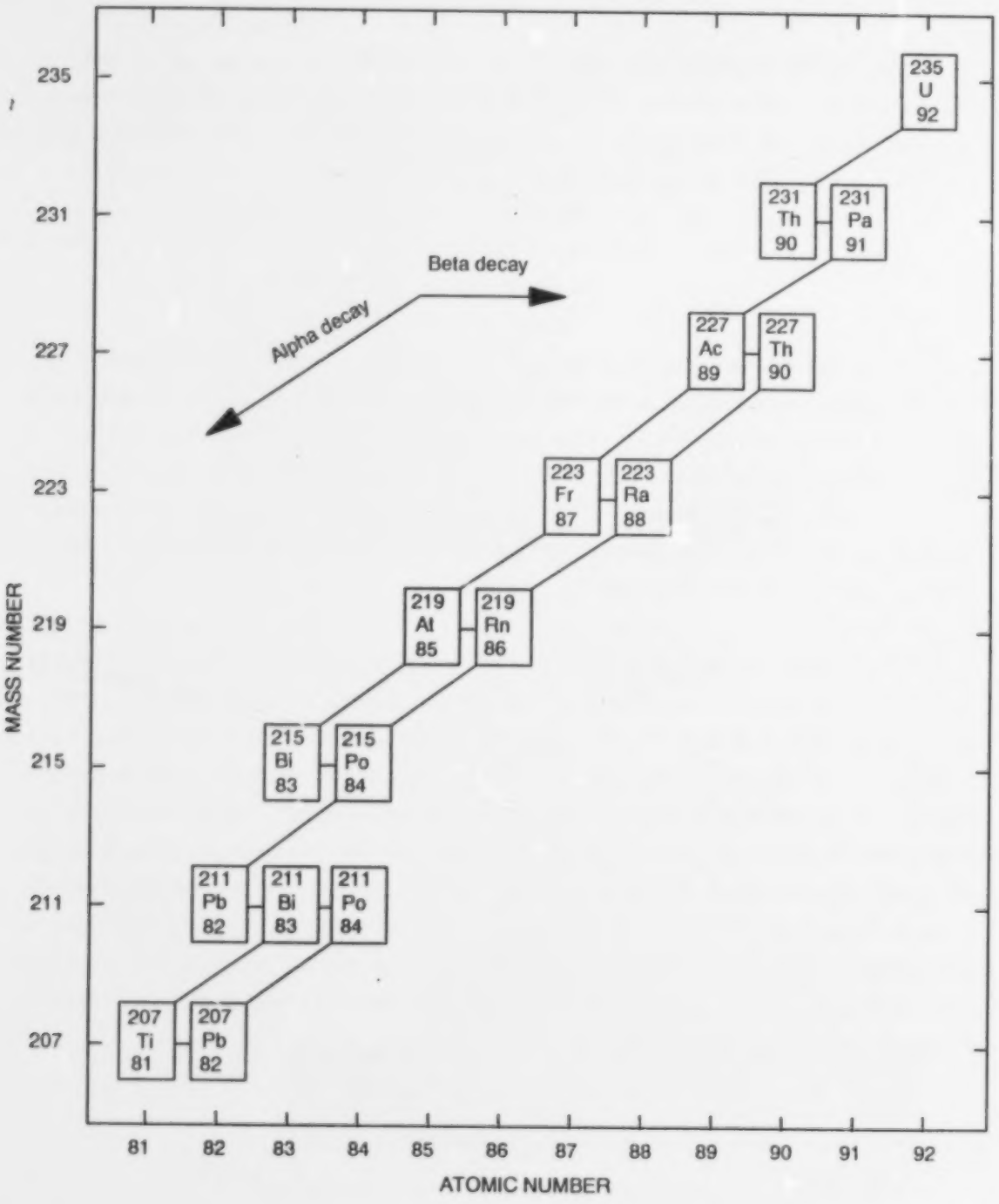

Figure 4.--The uranium-235 decay series.

Uranium and Thorium Decay Series

Uranium and thorium are members of the actinide series of elements. All nuclides in this series are radioactive. Concentrations in ground water for members of two uranium-decay series, ^{238}U and ^{235}U, and the thorium-decay series, ^{232}Th, are presented.

Total Uranium

Three naturally occurring isotopes of uranium are ^{238}U, ^{235}U, and ^{234}U, with relative abundances in the Earth's crust of 99.27, 0.71, and 0.0058 atom percent, respectively. In this report, uranium concentrations in ground water are given as totals of the three isotopes in picocuries per liter. A maximum contaminant level in drinking water has not been established by the U.S. Environmental Protection Agency for the individual isotopes of uranium or for total uranium.

Water samples were collected in 1981 from 13 public ground-water supply systems throughout Idaho and analyzed for total uranium (Horton, 1985). Total uranium concentrations ranged from 1.9±1.3 to 25.1±0.8 pCi/L and were distributed about a mean concentration of 9.6±1.8 pCi/L and a median concentration of 9.1±0.4 pCi/L (fig. 5). Water samples were collected in May 1989 from 12 wells and 3 irrigation wastewater drains about 65 mi southwest of the INEL (Mann and Knobel, 1990). Total uranium concentrations ranged from 1.4±0.1 to 5.3±0.5 pCi/L and were distributed about a mean concentration of 3.1±0.3 pCi/L and a median concentration of 3.0±0.3 pCi/L (fig. 5). Based on these data, background concentrations for total uranium in ground water in Idaho range from 0 to about 9 pCi/L.

Radium

Radium-226 and radium-228 are naturally occurring radioactive isotopes in the ^{238}U and ^{232}Th decay series, respectively. The maximum contaminant level for drinking water has been established at 5 pCi/L for combined ^{226}Ra

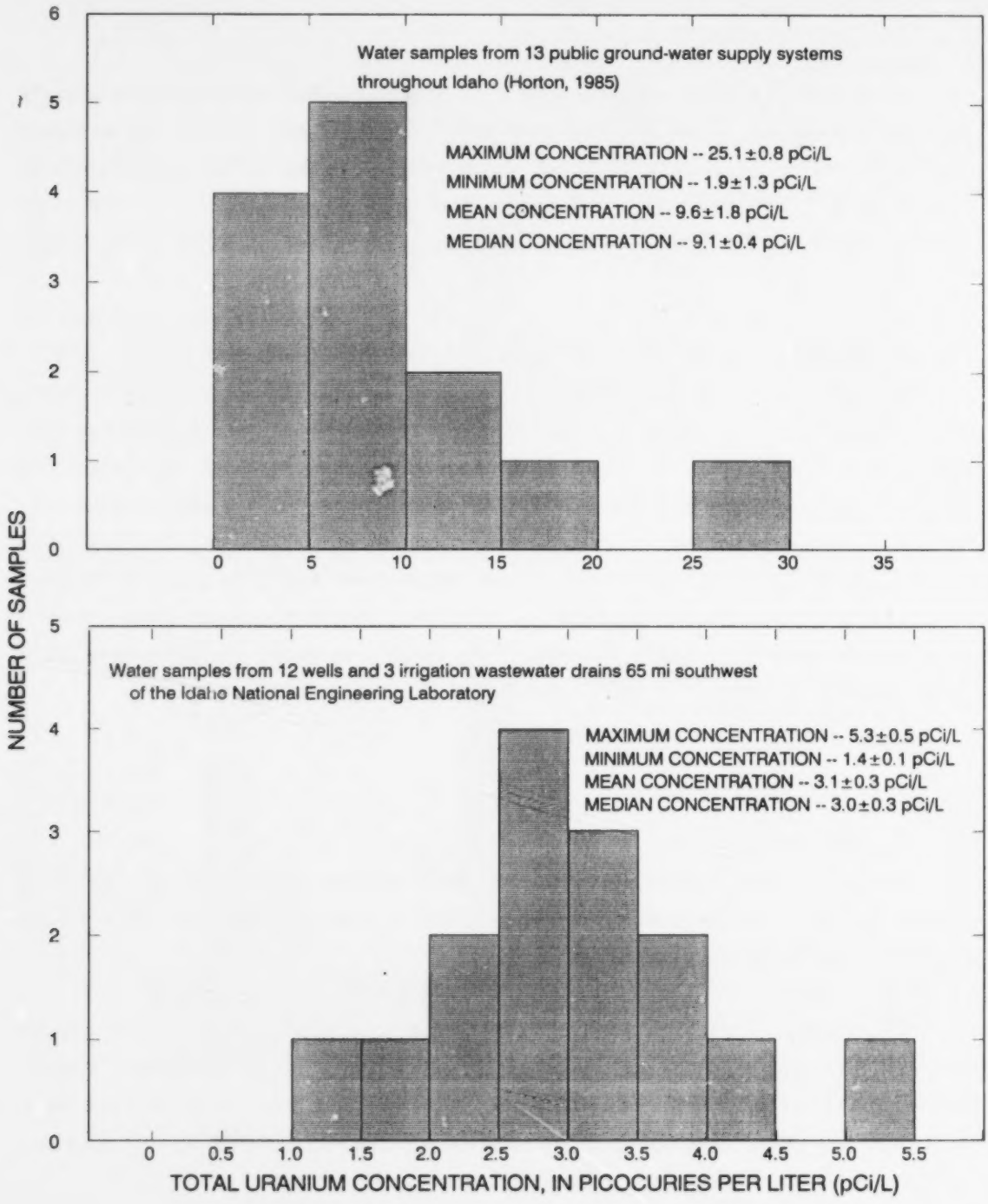
Water samples from 13 public ground-water supply systems throughout Idaho (Horton, 1985)
MAXIMUM CONCENTRATION -- 25.1±0.8 pCi/L
MINIMUM CONCENTRATION -- 1.9±1.3 pCi/L
MEAN CONCENTRATION -- 9.6±1.8 pCi/L
MEDIAN CONCENTRATION -- 9.1±0.4 pCi/L
Water samples from 12 wells and 3 irrigation wastewater drains 65 mi southwest of the Idaho National Engineering Laboratory
MAXIMUM CONCENTRATION -- 5.3±0.5 pCi/L
MINIMUM CONCENTRATION -- 1.4±0.1 pCi/L
MEAN CONCENTRATION -- 3.1±0.3 pCi/L
MEDIAN CONCENTRATION -- 3.0±0.3 pCi/L
NUMBER OF SAMPLES
0 1 2 3 4 5 6
0 5 10 15 20 25 30 35
0 1 2 3 4 5
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5
TOTAL URANIUM CONCENTRATION, IN PICOCURIES PER LITER (pCi/L)

Figure 5.--The distribution of total uranium concentrations in water samples in Idaho.

and ^{228}Ra concentrations (U.S. Environmental Protection Agency, 1989, p. 550).

Water samples were collected in 1981 from 13 public ground-water supply systems throughout Idaho and analyzed for ^{226}Ra (Horton, 1985). No analyses for ^{228}Ra were performed on these water samples. The ^{226}Ra concentrations ranged from 0.1±0.0 to 0.2±0.0 pCi/L and were distributed about a mean concentration of 0.1±0.02 pCi/L and a median concentration of 0.1±0.0 pCi/L.

Water samples were collected in May 1989 from 12 wells and 3 irrigation wastewater drains about 65 mi southwest of the INEL (Mann and Knobel, 1990). Concentrations of ^{226}Ra ranged from 0.00±0.01 to 0.15±0.02 pCi/L and were distributed about a mean concentration of 0.08±0.01 pCi/L and a median concentration of 0.09±0.02 pCi/L (fig. 6). Concentrations of ^{228}Ra ranged from -0.9±0.7 to 2.6±1.2 pCi/L and were distributed about a mean concentration of 0.4±0.2 pCi/L and a median concentration of 0.3±0.5 pCi/L (fig. 6). All 15 water samples had combined concentrations of ^{226}Ra plus ^{228}Ra less than the maximum contaminant level of 5 pCi/L. Based on these data, background concentrations for ^{226}Ra and ^{228}Ra in ground water in Idaho generally range from 0 to about 0.1 and 0 to 0.3 pCi/L, respectively.

Radon

Radon-222 is a naturally occurring radioactive noble gas in the ^{238}U decay series. A maximum contaminant level has not been set for ^{222}Rn dissolved in drinking water.

Water samples were collected in 1981 from 68 public ground-water supply systems throughout Idaho and analyzed for dissolved ^{222}Rn (Horton, 1985). Concentrations of ^{222}Rn ranged from -178±44 to 1,290±95 pCi/L and were distributed about a mean concentration of 300±35 pCi/L and a median concentration of 224±63 pCi/L (fig. 7).

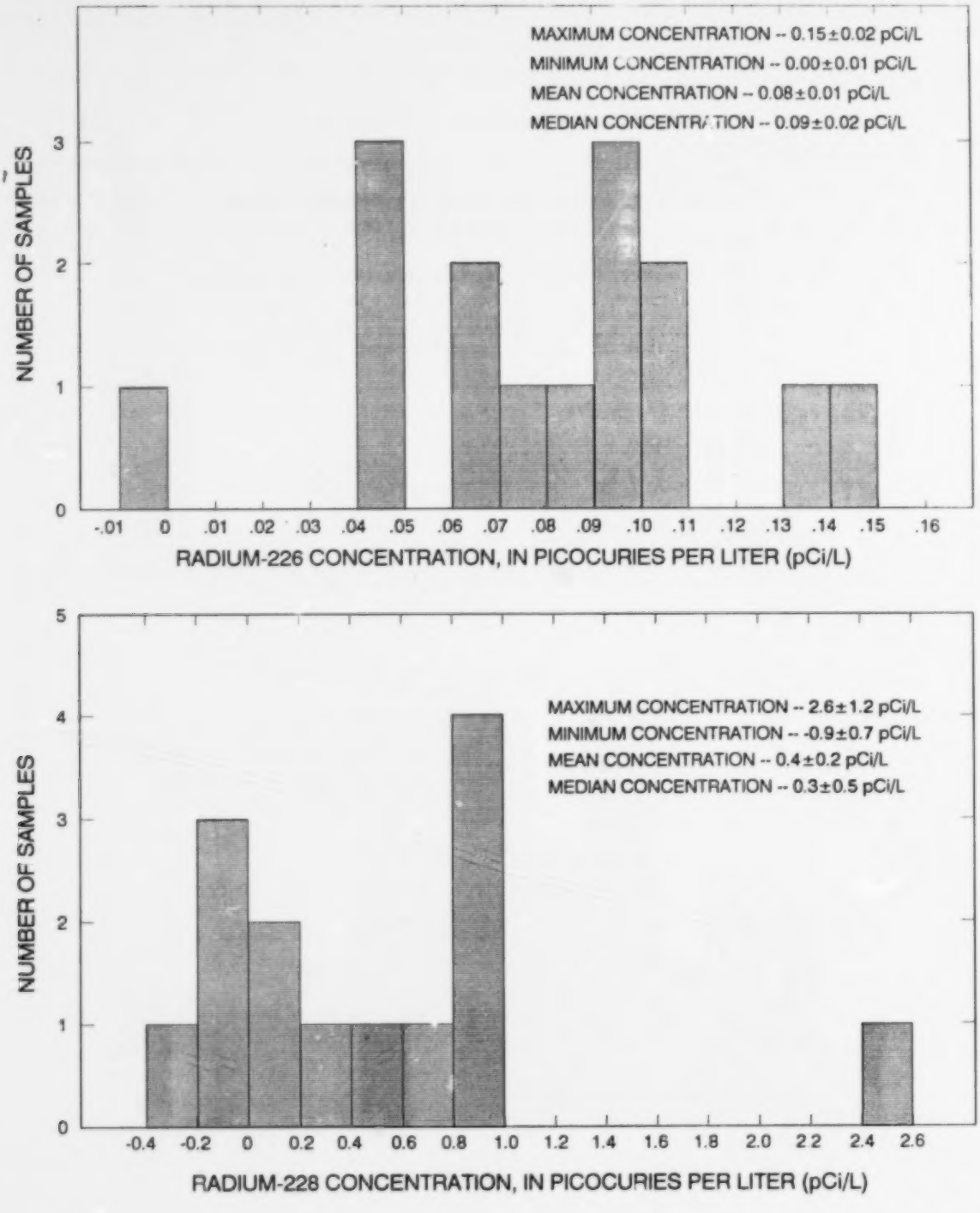

Figure 6.--The distribution of radium-226 and radium-228 concentrations in water samples from 12 wells and 3 irrigation wastewater drains 65 miles southwest of the Idaho National Engineering Laboratory.

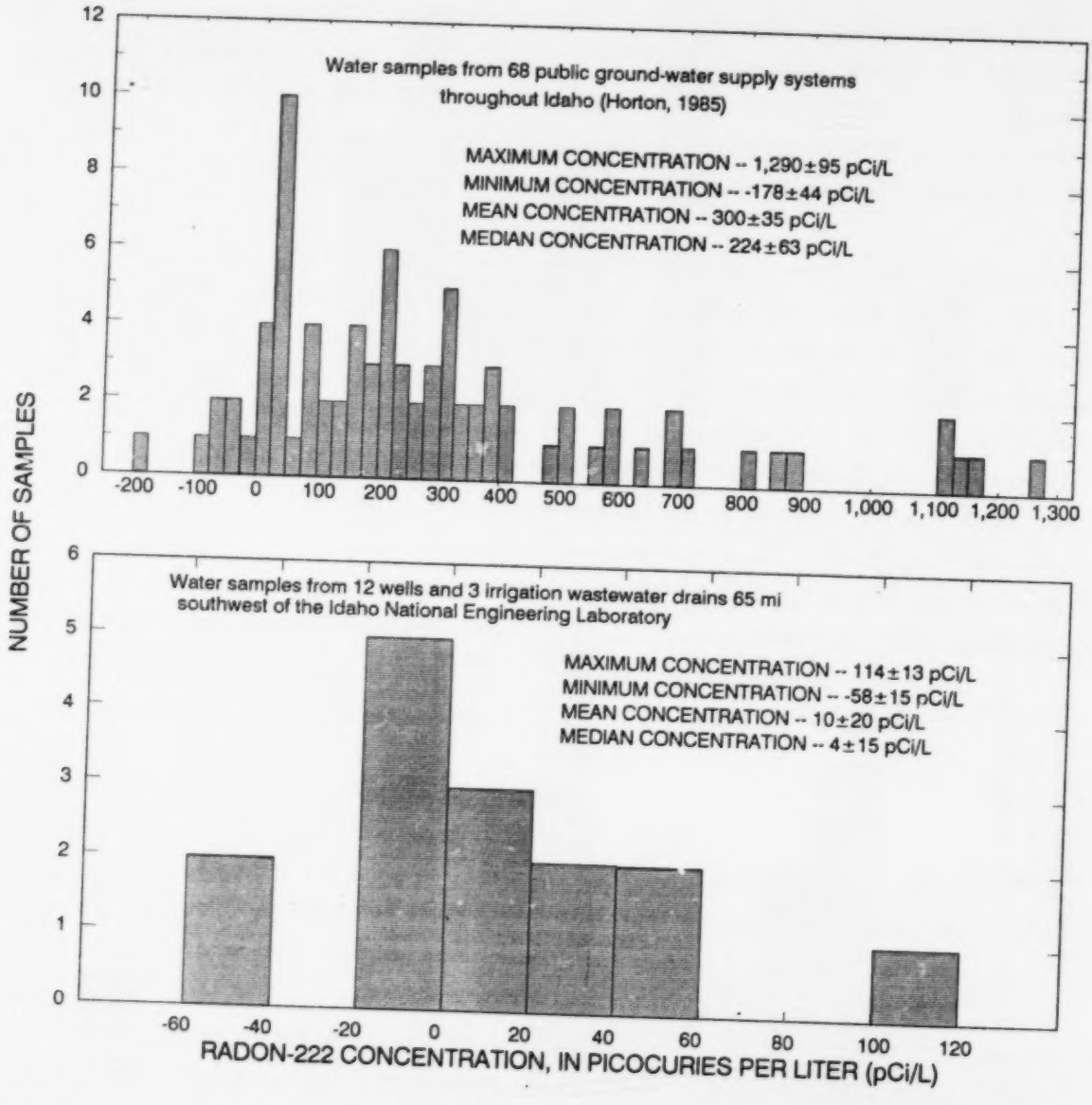
Water samples from 68 public ground-water supply systems throughout Idaho (Horton, 1985)
MAXIMUM CONCENTRATION -- 1,290±95 pCi/L
MINIMUM CONCENTRATION -- -178±44 pCi/L
MEAN CONCENTRATION -- 300±35 pCi/L
MEDIAN CONCENTRATION -- 224±63 pCi/L
Water samples from 12 wells and 3 irrigation wastewater drains 65 mi southwest of the Idaho National Engineering Laboratory
MAXIMUM CONCENTRATION -- 114±13 pCi/L
MINIMUM CONCENTRATION -- -58±15 pCi/L
MEAN CONCENTRATION -- 10±20 pCi/L
MEDIAN CONCENTRATION -- 4±15 pCi/L
NUMBER OF SAMPLES
RADON-222 CONCENTRATION, IN PICOCURIES PER LITER (pCi/L)

Figure 7.--The distribution of radon-222 concentrations in water samples in Idaho.

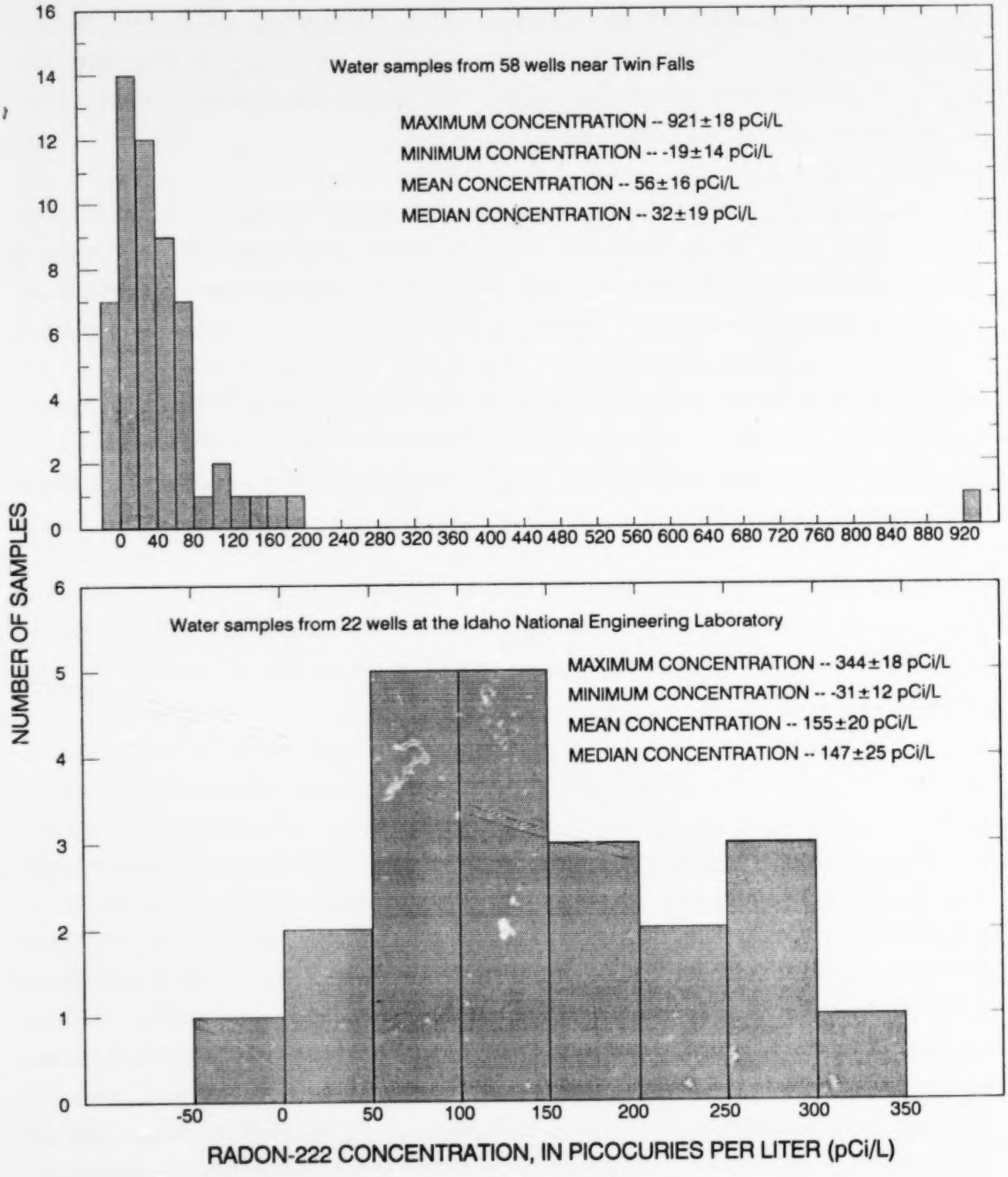
Water samples from 58 wells near Twin Falls
MAXIMUM CONCENTRATION -- 921±18 pCi/L
MINIMUM CONCENTRATION -- -19±14 pCi/L
MEAN CONCENTRATION -- 56±16 pCi/L
MEDIAN CONCENTRATION -- 32±19 pCi/L
0 40 80 120 160 200 240 280 320 360 400 440 480 520 560 600 640 680 720 760 800 840 880 920
Water samples from 22 wells at the Idaho National Engineering Laboratory
MAXIMUM CONCENTRATION -- 344±18 pCi/L
MINIMUM CONCENTRATION -- -31±12 pCi/L
MEAN CONCENTRATION -- 155±20 pCi/L
MEDIAN CONCENTRATION -- 147±25 pCi/L
-50 0 50 100 150 200 250 300 350
NUMBER OF SAMPLES
RADON-222 CONCENTRATION, IN PICOCURIES PER LITER (pCi/L)

Figure 7.--The distribution of radon-222 concentrations in water samples in Idaho--Continued.

Water samples were collected in May 1989 from 12 wells and 3 irrigation wastewater drains about 65 mi southwest of the INEL (Mann and Knobel, 1990). Concentrations of ^{222}Rn ranged from -58±15 to 114±13 pCi/L and were distributed about a mean concentration of 10±20 pCi/L and a median concentration of 4±15 pCi/L (fig. 7).

Concentrations of ^{222}Rn in water samples collected from 58 sites near Twin Falls in 1989 ranged from -19±14 to 921±18 pCi/L and were distributed about a mean concentration of 56±16 pCi/L and a median concentration of 32±19 pCi/L (fig. 7).

Water samples were collected from 22 wells at the INEL in 1989 and analyzed for dissolved ^{222}Rn. Concentrations of ^{222}Rn ranged from -31±12 to 344±18 pCi/L and were distributed about a mean concentration of 155±20 pCi/L and a median concentration of 147±25 pCi/L (fig. 7).

Dissolved ^{222}Rn concentrations can vary over a large range. Based on the data presented here, background concentrations for dissolved ^{222}Rn in ground water in Idaho generally range from 0 to about 250 pCi/L.

Transuranic Elements

Some transuranic elements may be produced in nature because of the availability of neutrons that can be captured by uranium isotopes. In pitchblende, the ratio of detectable ^{239}Pu to ^{238}U has ranged from 10^{-10} to 10^{-13}; in uranium minerals, the ratio of detectable ^{237}Np (neptunium-237) to ^{238}U has been 10^{-12} (Eisenbud, 1973, p. 164). Total uranium concentrations in basaltic rocks such as those that constitute the Snake River Plain aquifer are relatively small--around 1.2 ppm (parts per million) (Kaufman, 1972, p. 992). Given this small concentration of total uranium and the small ratio of transuranic elements to total uranium, background concentrations of the transuranium elements in water from the Snake River Plain aquifer should be zero.

Water samples were collected in September and October 1987 from 44 wells at the INEL and analyzed for ^{238}Pu and ^{239}, ^{240}Pu (undivided). Water samples were collected from 43 wells and analyzed for ^{241}Am (Knobel and Mann, 1988). Concentrations of ^{238}Pu ranged from -0.06±0.02 to 0.11±0.03 pCi/L and were distributed about a mean concentration of 0.004±0.004 pCi/L and a median concentration of 0.0±0.03 pCi/L (fig. 8). Concentrations of ^{239}, ^{240}Pu (undivided) ranged from -0.014±0.017 to 0.05±0.03 pCi/L and were distributed about a mean concentration of -0.0002±0.0019 pCi/L and a median concentration of -0.001±0.026 pCi/L (fig. 8). Concentrations of ^{241}Am ranged from -0.08±0.03 to 0.07±0.03 pCi/L and were distributed about a mean concentration of 0.012±0.005 pCi/L and a median concentration of 0.012±0.03 pCi/L (fig. 8). Based on these data, detectable background concentrations of transuranic elements in water in the Snake River Plain aquifer are not present. Operations at the INEL locally have affected concentrations of some transuranic elements in ground water.

Tritium

Tritium, a radioactive isotope of hydrogen, is formed in nature by interactions of cosmic rays with gases in the upper atmosphere. Tritium also is produced in thermonuclear detonations and is a waste product of the nuclear-power industry. The natural concentration of ^{3}H in surface water ranged from 5 to 20 pCi/L prior to atmospheric weapons testing (Eisenbud, 1973, p. 188). Concentrations of ^{3}H in surface water in the northern hemisphere were at a maximum of about 4,000 pCi/L in the mid-1960's as a result of thermonuclear explosions in the atmosphere. By the late 1970's, ^{3}H concentrations in surface water in the United States had decreased to an average of about 150 pCi/L (National Council on Radiation Protection and Measurements, 1979, p. 78). Background concentrations of ^{3}H in ground water in Idaho generally range from 75 to 150 pCi/L (Michel, 1989). The maximum contaminant level for ^{3}H in drinking water is 20,000 pCi/L (U.S. Environmental Protection Agency, 1989, p. 551).

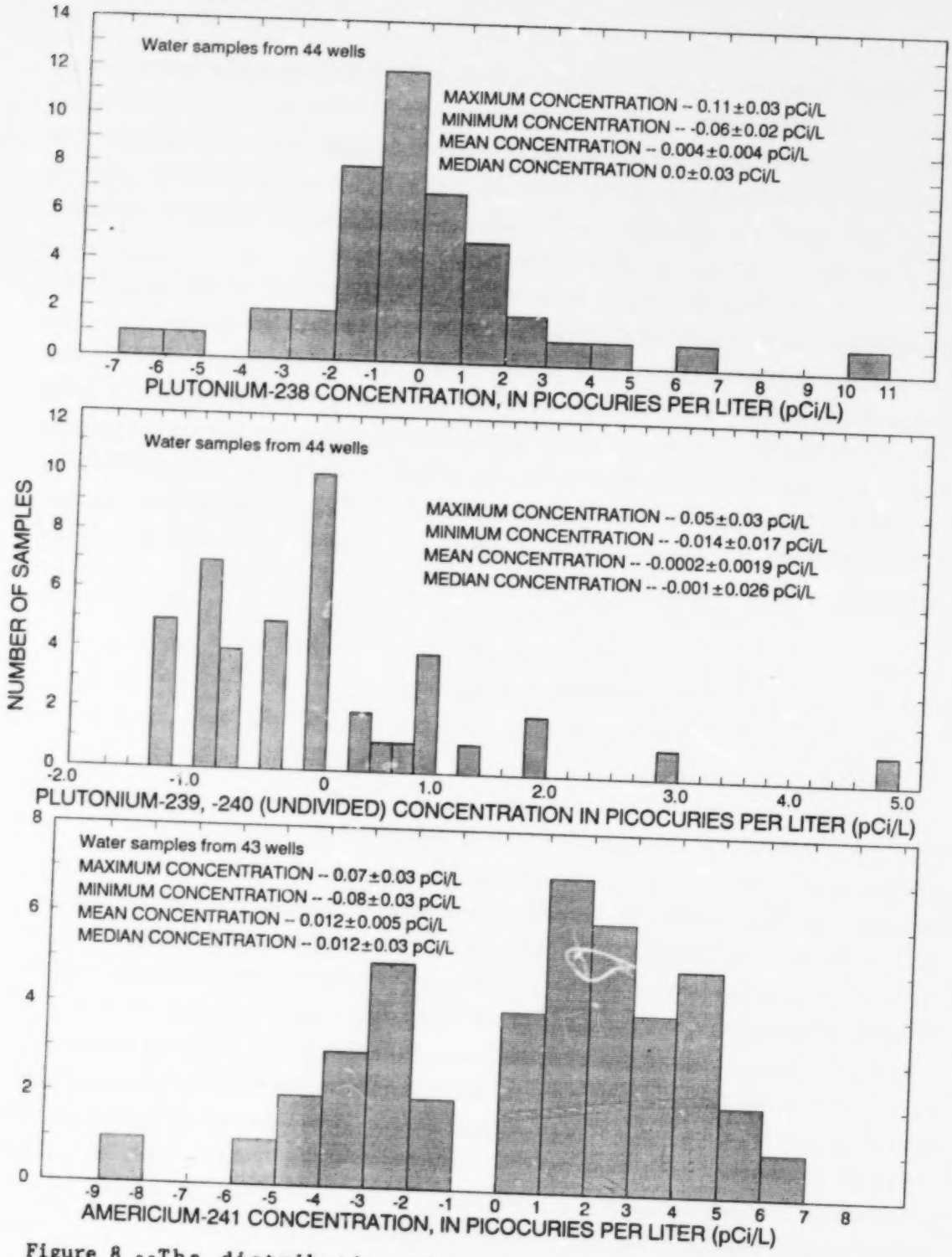
Water samples from 44 wells
MAXIMUM CONCENTRATION -- 0.11±0.03 pCi/L
MINIMUM CONCENTRATION -- -0.06±0.02 pCi/L
MEAN CONCENTRATION -- 0.004±0.004 pCi/L
MEDIAN CONCENTRATION 0.0±0.03 pCi/L
PLUTONIUM-238 CONCENTRATION, IN PICOCURIES PER LITER (pCi/L)
Water samples from 44 wells
MAXIMUM CONCENTRATION -- 0.05±0.03 pCi/L
MINIMUM CONCENTRATION -- -0.014±0.017 pCi/L
MEAN CONCENTRATION -- -0.0002±0.0019 pCi/L
MEDIAN CONCENTRATION -- -0.001±0.026 pCi/L
NUMBER OF SAMPLES
PLUTONIUM-239, -240 (UNDIVIDED) CONCENTRATION IN PICOCURIES PER LITER (pCi/L)
Water samples from 43 wells
MAXIMUM CONCENTRATION -- 0.07±0.03 pCi/L
MINIMUM CONCENTRATION -- -0.08±0.03 pCi/L
MEAN CONCENTRATION -- 0.012±0.005 pCi/L
MEDIAN CONCENTRATION -- 0.012±0.03 pCi/L
AMERICIUM-241 CONCENTRATION, IN PICOCURIES PER LITER (pCi/L)

Figure 8.--The distribution of plutonium-238, plutonium-239, -240 (undivided), and americium-241 concentrations in water samples at the Idaho National Engineering Laboratory.

Water samples were collected in May 1989 from 12 wells and 3 irrigation wastewater drains about 65 mi southwest of the INEL (Mann and Knobel, 1990). Concentrations of ^{3}H ranged from -10±13 to 106±13 pCi/L and were distributed about a mean concentration of 42±9 pCi/L and a median concentration of 35±13 pCi/L (fig. 9).

Water samples collected in September and October 1987 from 81 wells at the INEL were analyzed for ^{3}H (Knobel and Mann, 1988, p. 16). Concentrations of ^{3}H ranged from -300±300 to 80,600±1,500 pCi/L and were distributed about a mean concentration of 8,190±2,080 pCi/L and a median concentration of 100±300 pCi/L (fig. 9). These data clearly illustrate that wastewater-disposal practices at the INEL locally have increased tritium concentrations in ground water.

Strontium-90

Strontium-90 does not occur naturally with the exception of natural reactors such as Oklo, where nuclear fission reactions have occurred in an uranium-enriched deposit (Durrance, 1986, p. 90). This radionuclide is anthropogenically present in ground water as a fission product of nuclear-weapons tests and as a result of disposal practices in the nuclear industry. The maximum contaminant level for ^{90}Sr in drinking water is 8 pCi/L (U.S. Environmental Protection Agency, 1989, p. 551).

Water samples were collected in 1989 from 12 wells and 3 irrigation-wastewater drains about 65 mi southwest of the INEL (Mann and Knobel, 1990). Dissolved concentrations of ^{90}Sr in these samples ranged from -0.22±0.08 to 0.48±0.07 pCi/L and were distributed about a mean concentration of 0.07±0.05 pCi/L and a median concentration of 0.09±0.04 pCi/L (fig. 10). The analytical method detection limit for these ^{90}Sr analyses was 0.5 pCi/L.

Water samples collected in October 1988 from 80 wells at the INEL were analyzed for ^{90}Sr. Dissolved ^{90}Sr concentrations in these samples ranged from -2.9±1.4 to 48±3 pCi/L and were distributed about a mean concentration of 5.0±1.7 pCi/L and a median concentration of 1.0±2.0 pCi/L (fig. 10). The

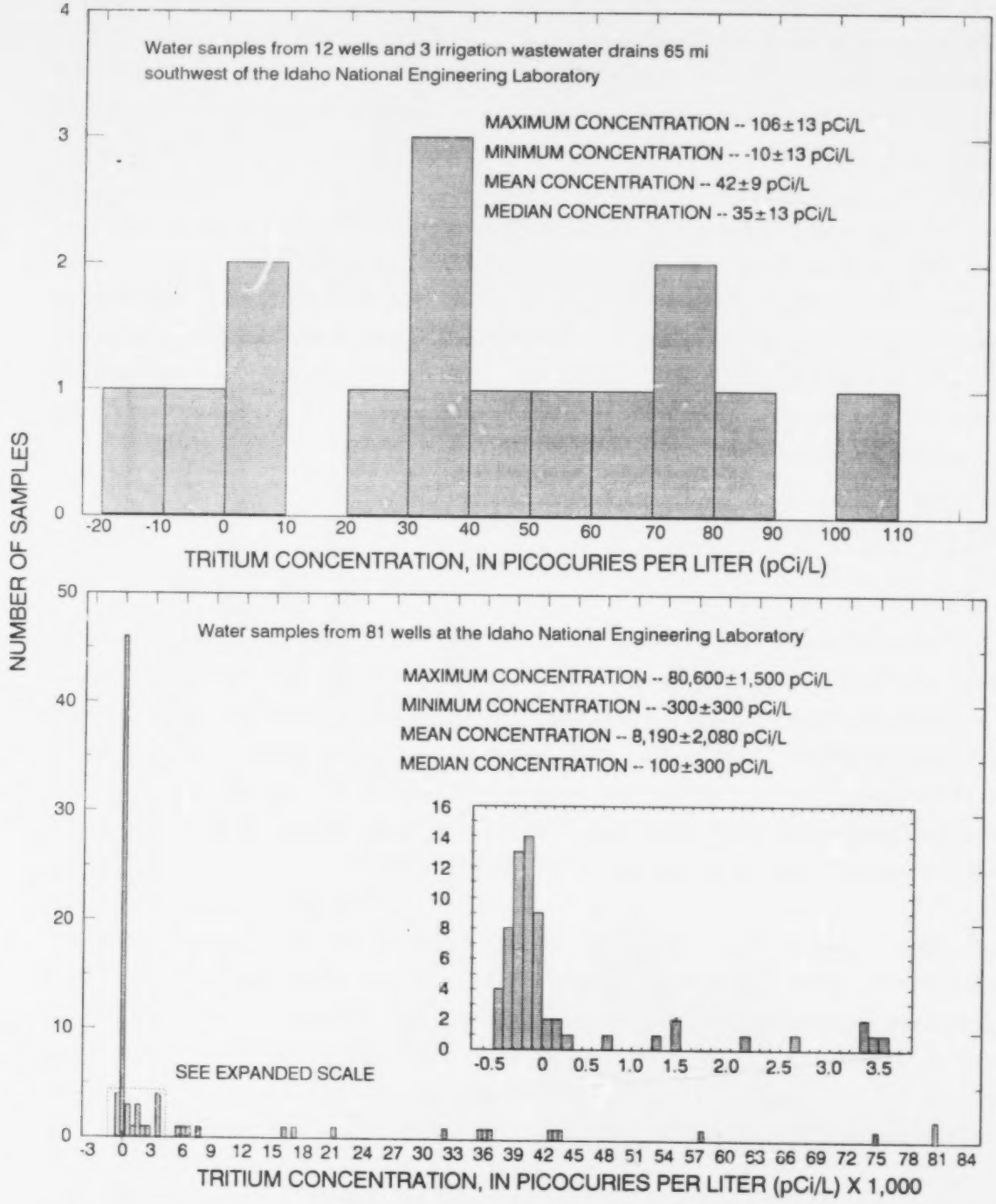
Water samples from 12 wells and 3 irrigation wastewater drains 65 mi southwest of the Idaho National Engineering Laboratory
MAXIMUM CONCENTRATION -- 106±13 pCi/L
MINIMUM CONCENTRATION -- -10±13 pCi/L
MEAN CONCENTRATION -- 42±9 pCi/L
MEDIAN CONCENTRATION -- 35±13 pCi/L
NUMBER OF SAMPLES
TRITIUM CONCENTRATION, IN PICOCURIES PER LITER (pCi/L)
Water samples from 81 wells at the Idaho National Engineering Laboratory
MAXIMUM CONCENTRATION -- 80,600±1,500 pCi/L
MINIMUM CONCENTRATION -- -300±300 pCi/L
MEAN CONCENTRATION -- 8,190±2,080 pCi/L
MEDIAN CONCENTRATION -- 100±300 pCi/L
SEE EXPANDED SCALE
TRITIUM CONCENTRATION, IN PICOCURIES PER LITER (pCi/L) X 1,000

Figure 9.--The distribution of tritium concentrations in water samples in Idaho.

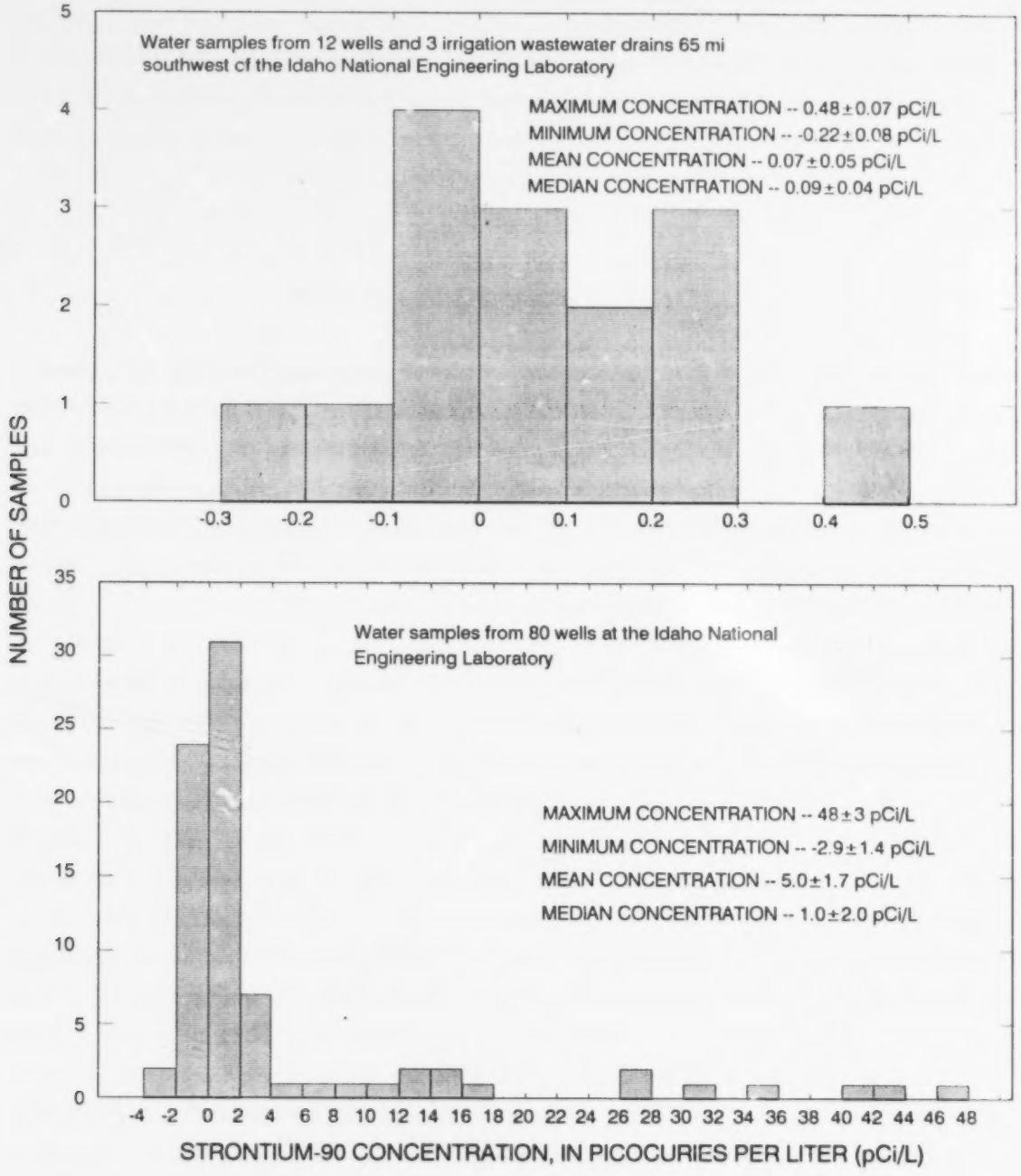
Water samples from 12 wells and 3 irrigation wastewater drains 65 mi southwest of the Idaho National Engineering Laboratory
MAXIMUM CONCENTRATION -- 0.48±0.07 pCi/L
MINIMUM CONCENTRATION -- -0.22±0.08 pCi/L
MEAN CONCENTRATION -- 0.07±0.05 pCi/L
MEDIAN CONCENTRATION -- 0.09±0.04 pCi/L
Water samples from 80 wells at the Idaho National Engineering Laboratory
MAXIMUM CONCENTRATION -- 48±3 pCi/L
MINIMUM CONCENTRATION -- -2.9±1.4 pCi/L
MEAN CONCENTRATION -- 5.0±1.7 pCi/L
MEDIAN CONCENTRATION -- 1.0±2.0 pCi/L
NUMBER OF SAMPLES
STRONTIUM-90 CONCENTRATION, IN PICOCURIES PER LITER (pCi/L)

Figure 10.--The distribution of strontium-90 concentrations in water samples in Idaho.

largest concentrations are in water from wells within the ^{90}Sr plume at the INEL. The analytical method detection limit for these analyses was 5 pCi/L. Based on the limited data from sites 65 mi southwest of the INEL, background concentrations of ^{90}Sr in water from the Snake River Plain aquifer generally are zero. Operations at the INEL locally have affected concentrations of ^{90}Sr in water in the Snake River Plain aquifer.

Iodine-129

Iodine-129 occurs both naturally and anthropogenically in ground water. Anthropogenic ^{129}I is produced by the fission of ^{235}U and ^{239}Pu. The largest source is from the reprocessing of spent nuclear fuels (Mann and others, 1988, p. 9). The maximum contaminant level for manmade radiation of 4 mrem/yr dose equivalent to the total body or any organ (U.S. Environmental Protection Agency, 1989, p. 550) is achieved at an ^{129}I concentration in drinking water of 1 pCi/L (Mann and others, 1988, p. 23).

Water samples collected in 1981 from 33 wells at the INEL were analyzed for dissolved concentrations of ^{129}I (Mann and others, 1988, p. 11). Of these, concentrations in seven wells not influenced by waste-disposal sites at the INEL were below the reporting level of three times the sample standard deviation. Concentrations of ^{129}I in these seven water samples ranged from 0.01±0.01 to 0.10±0.10 pCi/L and were distributed about a mean concentration of 0.05±0.01 pCi/L and a median concentration of 0.05±0.01 pCi/L. Based on these data, background concentrations of ^{129}I in water from the Snake River Plain aquifer generally range from 0 to 0.05 pCi/L.

Water samples collected in 1986 from 35 wells were analyzed for dissolved concentrations of ^{129}I. Concentrations in these samples ranged from -0.15±0.13 to 3.6±0.4 pCi/L and were distributed about a mean concentration of 1.19±0.20 pCi/L and a median concentration of 0.65±0.16 pCi/L (fig. 11). These concentrations, compared with concentrations in the samples collected in 1981 from the same wells, show that facility operations locally have affected ^{129}I concentrations in water in the Snake River Plain aquifer beneath part of the INEL.

Gross Measurements of Radioactivity

Gross analyses involve the measurement of total radioactivity as either alpha- or beta-particle radiation given off during the decay process. Generally, laboratories report the analytical results referenced to one particular alpha- or beta-particle emitter.

Gross Alpha-Particle Radioactivity

In this report, gross alpha-particle concentrations in ground water are given as total--both the suspended and dissolved fractions--and are reported in picocuries per liter as natural uranium. The maximum contaminant level for gross alpha-particle radioactivity in drinking water is 15 pCi/L, excluding the alpha-particle contribution to the radioactivity from radon and uranium (U.S. Environmental Protection Agency, 1989, p. 550).

Water samples were collected in 1981 from 68 different public ground-water supply systems throughout Idaho (Horton, 1985). Gross alpha-particle concentrations ranged from -0.2±0.2 to 18.0±1.3 pCi/L and were distributed about a mean concentration of 2.6±0.5 pCi/L and a median concentration of 1.3±0.4 pCi/L (fig. 12).

Water samples were collected in May 1989 from 12 wells and 3 irrigation wastewater drains about 65 mi southwest of the INEL (Mann and Knobel, 1990). Gross alpha-particle concentrations ranged from 2.1±0.3 to 16.0±2.2 pCi/L and were distributed about a mean concentration of 4.4±0.9 pCi/L and a median concentration of 4.0±0.4 pCi/L (fig. 12).

Between February and May 1989, water from 19 wells at the INEL was analyzed for gross alpha-particle radioactivity. Concentrations ranged from 0.3±0.6 to 5.1±0.8 pCi/L and were distributed about a mean concentration of 2.7±0.3 pCi/L and a median concentration of 2.4±0.5 pCi/L (fig. 12). Background concentrations for gross alpha-particle radioactivity in ground water in Idaho generally range from 0 to about 5 pCi/L.

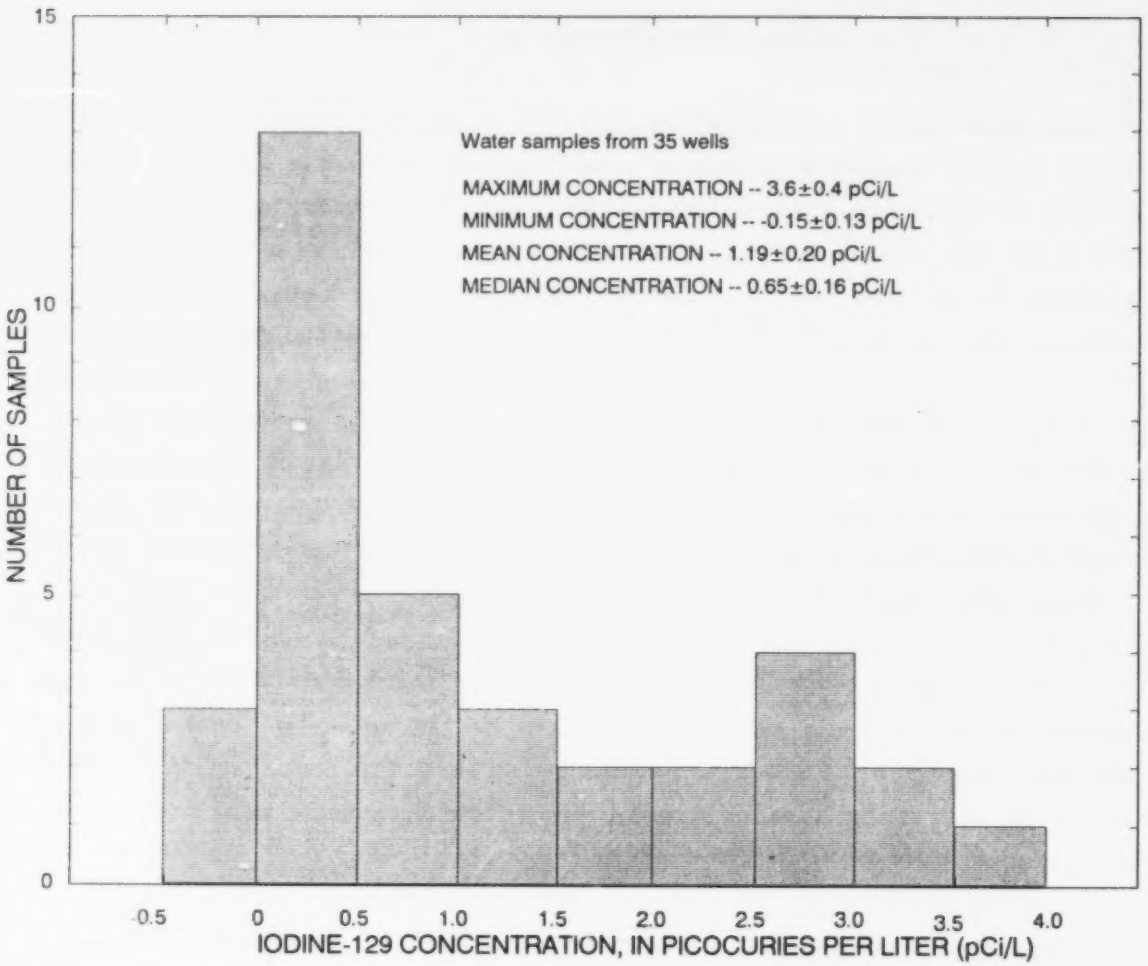

Figure 11.--The distribution of iodine-129 concentrations in water samples at the Idaho National Engineering Laboratory.

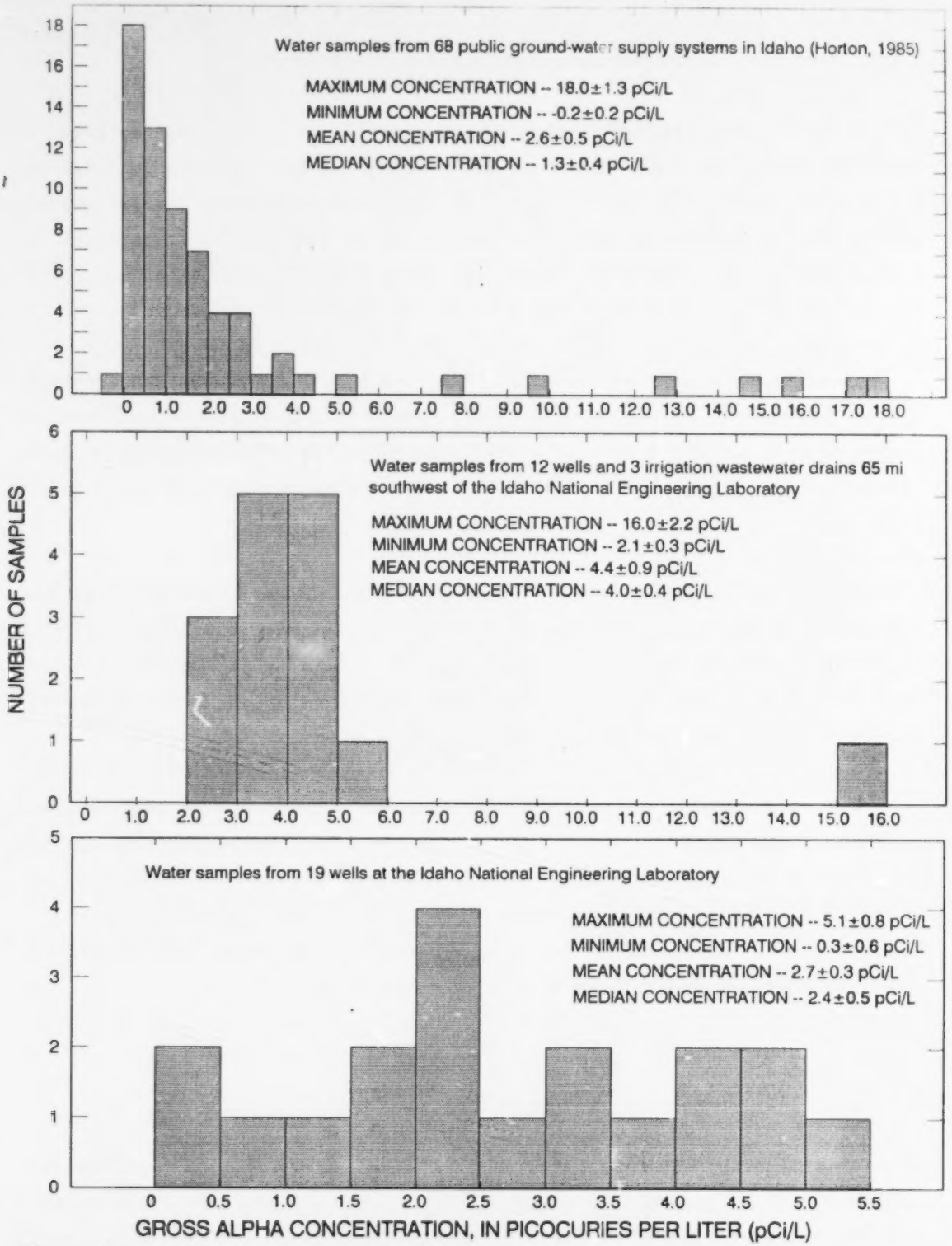
Water samples from 68 public ground-water supply systems in Idaho (Horton, 1985)
MAXIMUM CONCENTRATION -- 18.0±1.3 pCi/L
MINIMUM CONCENTRATION -- -0.2±0.2 pCi/L
MEAN CONCENTRATION -- 2.6±0.5 pCi/L
MEDIAN CONCENTRATION -- 1.3±0.4 pCi/L
Water samples from 12 wells and 3 irrigation wastewater drains 65 mi southwest of the Idaho National Engineering Laboratory
MAXIMUM CONCENTRATION -- 16.0±2.2 pCi/L
MINIMUM CONCENTRATION -- 2.1±0.3 pCi/L
MEAN CONCENTRATION -- 4.4±0.9 pCi/L
MEDIAN CONCENTRATION -- 4.0±0.4 pCi/L
Water samples from 19 wells at the Idaho National Engineering Laboratory
MAXIMUM CONCENTRATION -- 5.1±0.8 pCi/L
MINIMUM CONCENTRATION -- 0.3±0.6 pCi/L
MEAN CONCENTRATION -- 2.7±0.3 pCi/L
MEDIAN CONCENTRATION -- 2.4±0.5 pCi/L
NUMBER OF SAMPLES
GROSS ALPHA CONCENTRATION, IN PICOCURIES PER LITER (pCi/L)

Figure 12.--The distribution of gross alpha-particle concentrations in water samples in Idaho.

Gross Beta-Particle Radioactivity

Gross beta-particle concentrations in ground water are given as total--both the suspended and dissolved fractions--and are reported in pCi/L as ^{137}Cs. The maximum contaminant level is established on an average annual concentration assumed to produce a total body or organ dose of 4 mrem/yr of beta-particle radiation. For comparison purposes, the average annual concentration of ^{137}Cs that produces a 4 mrem/yr dose is 120 pCi/L.

Water samples were collected in 1981 from 68 public ground-water supply systems throughout Idaho (Horton, 1985). Gross beta-particle concentrations ranged from -1.1±0.9 to 18.8±1.0 pCi/L and were distributed about a mean concentration of 3.6±0.5 pCi/L and a median concentration of 2.6±1.3 pCi/L (fig. 13).

Water samples were collected in May 1989 from 12 wells and 3 irrigation wastewater drains about 65 mi southwest of the INEL (Mann and Knobel, 1990). Gross beta-particle concentrations ranged from 2.9±0.8 to 19.0±1.6 pCi/L and were distributed about a mean concentration of 8.4±1.1 pCi/L and a median concentration 7.5±1.3 pCi/L (fig. 13).

Between February and May 1989 water samples from 18 wells at the INEL were analyzed for gross beta-particle radioactivity. Concentrations ranged from -1±2 to 11±2 pCi/L and were distributed about a mean concentration of 5.1±0.7 pCi/L and a median concentration of 5.0±1.3 pCi/L (fig. 13). Background concentrations for gross beta-particle radioactivity in ground water in Idaho generally range from 0 to about 8 pCi/L.

Gamma-Ray Spectrometry

Gamma-emitting radionuclides identified using gamma spectrometry include ^{137}Cs, ^{60}Co, and ^{40}K. Background concentrations of these radionuclides are presented in the following sections.

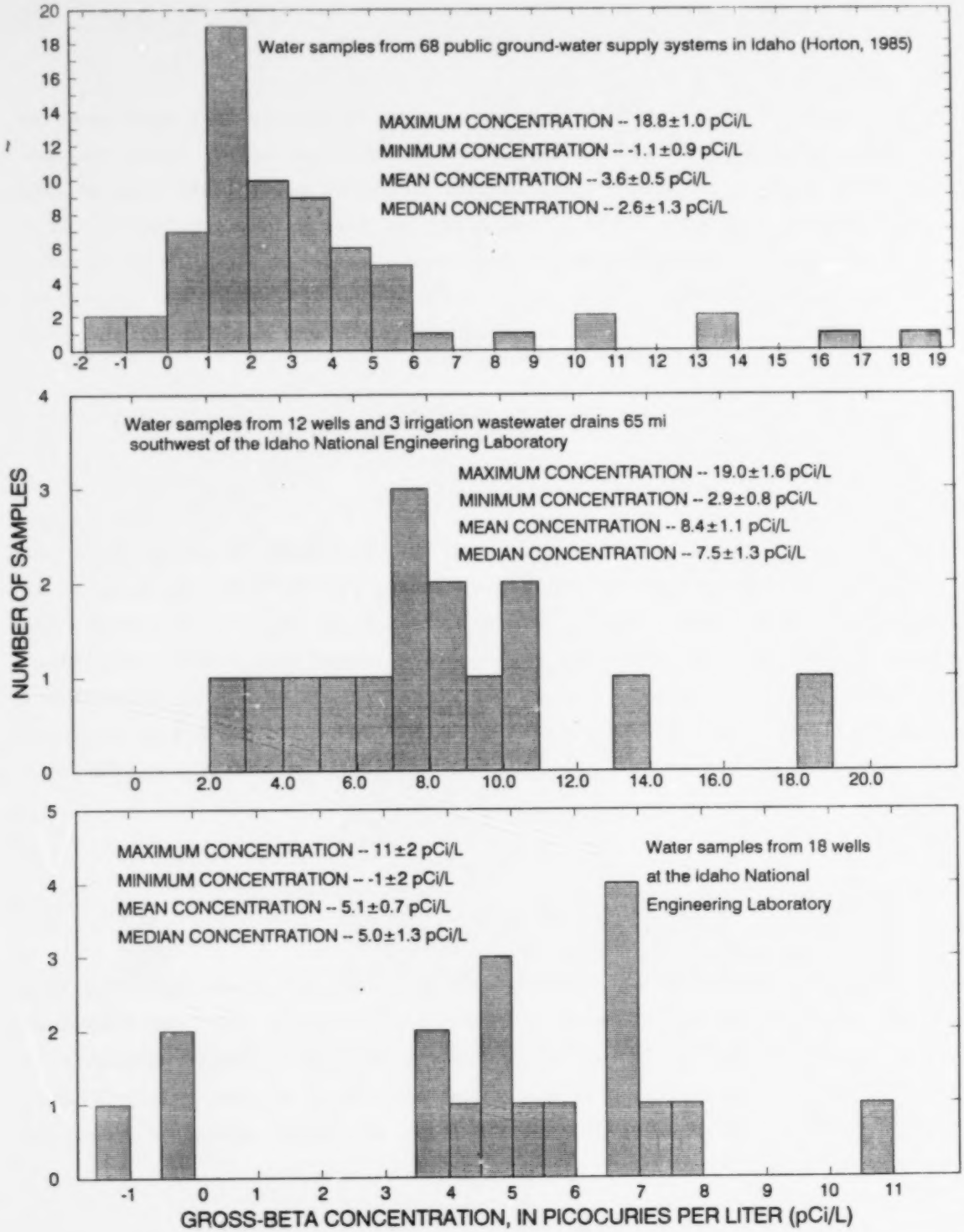
Water samples from 68 public ground-water supply systems in Idaho (Horton, 1985)
MAXIMUM CONCENTRATION -- 18.8±1.0 pCi/L
MINIMUM CONCENTRATION -- -1.1±0.9 pCi/L
MEAN CONCENTRATION -- 3.6±0.5 pCi/L
MEDIAN CONCENTRATION -- 2.6±1.3 pCi/L
Water samples from 12 wells and 3 irrigation wastewater drains 65 mi southwest of the Idaho National Engineering Laboratory
MAXIMUM CONCENTRATION -- 19.0±1.6 pCi/L
MINIMUM CONCENTRATION -- 2.9±0.8 pCi/L
MEAN CONCENTRATION -- 8.4±1.1 pCi/L
MEDIAN CONCENTRATION -- 7.5±1.3 pCi/L
MAXIMUM CONCENTRATION -- 11±2 pCi/L
MINIMUM CONCENTRATION -- -1±2 pCi/L
MEAN CONCENTRATION -- 5.1±0.7 pCi/L
MEDIAN CONCENTRATION -- 5.0±1.3 pCi/L
Water samples from 18 wells at the Idaho National Engineering Laboratory
NUMBER OF SAMPLES
GROSS-BETA CONCENTRATION, IN PICOCURIES PER LITER (pCi/L)

Figure 13.--The distribution of gross beta-particle concentrations in water samples in Idaho.

Cesium-137

Cesium-137 is not naturally occurring but is present in ground water as a fission product from nuclear facilities and weapons tests. Concentrations of ^{137}Cs were reported in water samples collected during 1987 from 48 INEL wells (Knobel and Mann, 1988). Concentrations ranged from -60±40 to 70±30 pCi/L and were distributed about a mean concentration of 7.7±3.9 pCi/L and a median concentration of 6.0±14.0 pCi/L (fig. 14). The background concentration of ^{137}Cs in water from the Snake River Plain aquifer at the INEL generally is zero.

Cobalt-60

Cobalt-60 is not naturally occurring but is present in ground water as a product of the nuclear industry. Concentrations of ^{60}Co were reported in water samples collected from 12 wells at the INEL during 1980-81 (Knobel and Mann, 1988). Concentrations in these samples ranged from -10±6.6 to 7.9±6.3 pCi/L and were distributed about a mean concentration of 1.54±1.40 pCi/L and a median concentration of 1.47±0.11 pCi/L (fig. 15). The background concentration of ^{60}Co in water from the Snake River Plain aquifer at the INEL generally is zero.

Potassium-40

Potassium-40 is a naturally occurring isotope of potassium. Potassium is one of the major rock-forming elements in the Earth's crust and comprises 2.6 percent of the continental crustal material. The relative abundance of ^{40}K is 0.0122 weight percent of the total abundance of potassium (Kretz, 1972, p. 971). Weathering of granitic rocks is a major source of potassium in ground water.

Total potassium concentrations were determined in water samples collected in 1989 from 17 wells and 1 spring at the INEL. Concentrations ranged from 2.4 to 7.0 mg/L and were distributed about a mean concentration

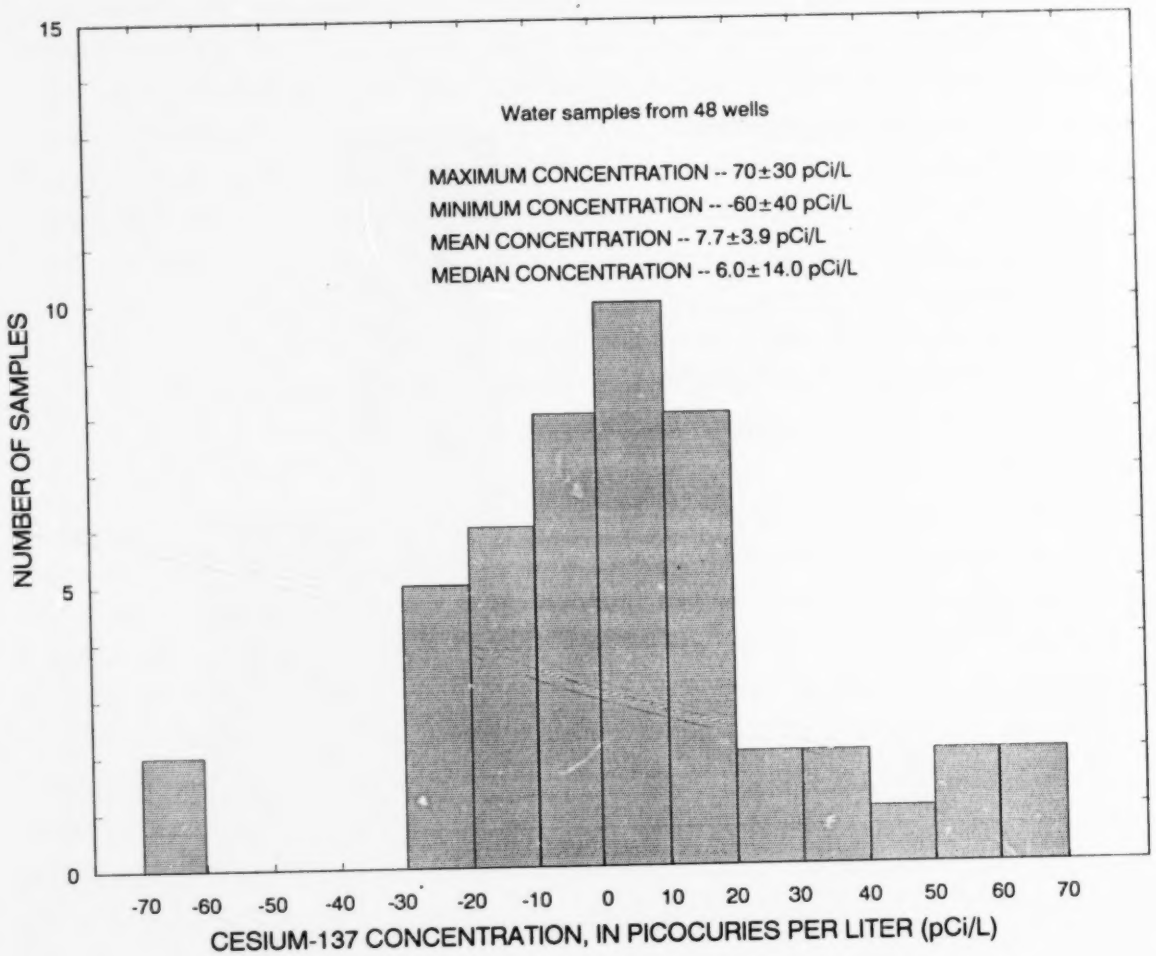
Water samples from 48 wells
MAXIMUM CONCENTRATION -- 70±30 pCi/L
MINIMUM CONCENTRATION -- -60±40 pCi/L
MEAN CONCENTRATION -- 7.7±3.9 pCi/L
MEDIAN CONCENTRATION -- 6.0±14.0 pCi/L
NUMBER OF SAMPLES
0
5
10
15
-70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70
CESIUM-137 CONCENTRATION, IN PICOCURIES PER LITER (pCi/L)

Figure 14.--The distribution of cesium-137 concentrations in water samples at the Idaho National Engineering Laboratory.

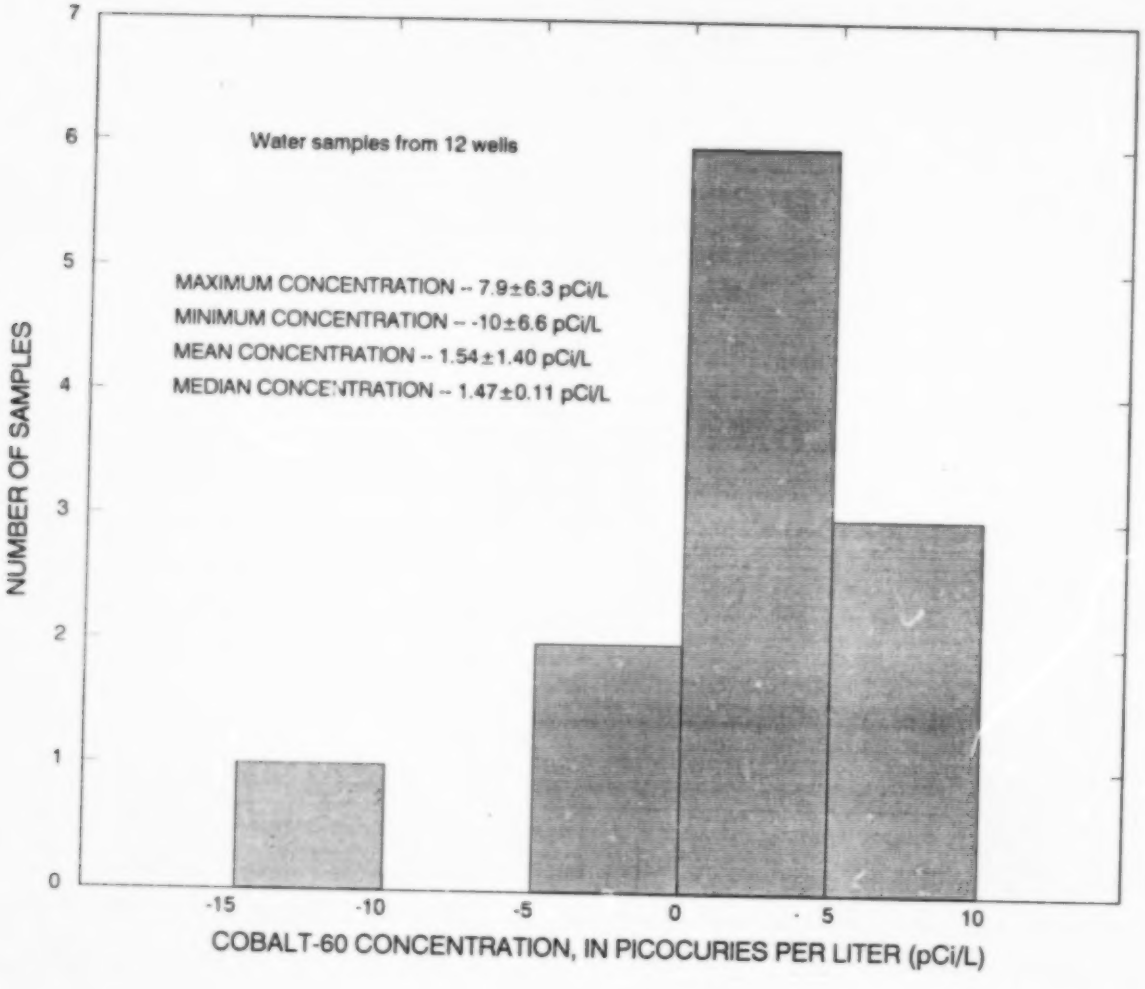

Figure 15.--The distribution of cobalt-60 concentrations in water samples at the Idaho National Engineering Laboratory.

of 3.58 mg/L and a median concentration of 3.15 mg/L. The background concentration of ^{40}K in ground water at the INEL was estimated to be about 300 pCi/L using the relative weight percent of 0.0122 with respect to the median potassium concentration of 3.15 mg/L and the specific activity of 6.8×10^{-6} Ci/g.

Water samples from seven INEL wells were analyzed for dissolved concentrations of ^{40}K. Concentrations ranged from 10±9 to 800±300 pCi/L and were distributed about a mean concentration of 390±116 pCi/L and a median concentration of 400±400 pCi/L (fig. 16). The concentration of ^{40}K in a water sample collected from the Big Lost River near Arco was 800±400 pCi/L, within the same order of magnitude as the ground-water samples. Concentrations of ^{40}K in water from these sites were less than the reporting level.

BACKGROUND CONCENTRATIONS OF SELECTED ORGANIC COMPOUNDS AND INORGANIC CHEMICAL CONSTITUENTS

Selected organic compounds and inorganic chemical constituents that have maximum contaminant levels for drinking water established by Congress pursuant to the recommendations of the U.S. Environmental Protection Agency (1989, p. 547-548, 608) are discussed in this report. The mean and median concentrations were used where possible to estimate background concentrations of organic compounds and inorganic chemical constituents. For those compounds and constituents where most concentrations were less than the analytical method detection limit, the background concentration was estimated to be less than the limit.

Selected Organic Compounds

Organic compounds in this report include purgeable organic compounds and pesticides. These organic compounds and their respective maximum contaminant levels are listed in table 1.

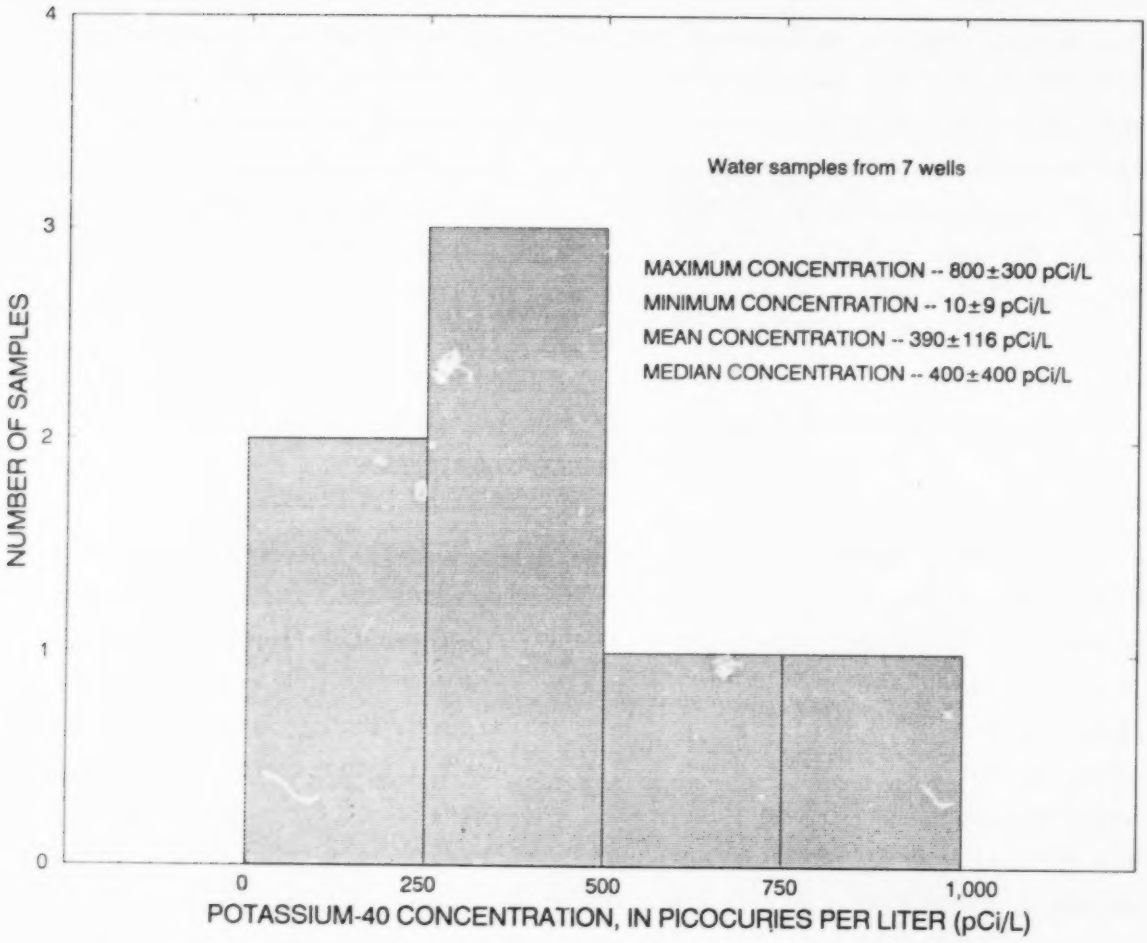

Figure 16.--The distribution of potassium-40 concentrations in water samples at the Idaho National Engineering Laboratory.

Table 1.--Organic compounds for which maximum contaminant levels have been established

[Maximum contaminant level: A indicates that total trihalomethanes--which includes bromoform, chloroform, dibromochloromethane, and dichlorobromomethane--in community water systems serving 10,000 or more persons and that add a disinfectant (oxidant) to the water in any part of the drinking water treatment process cannot exceed 100 micrograms per liter (U.S. Environmental Protection Agency, 1989, p. 548); maximum contaminant levels for purgeable organic compounds apply to community water systems and non-transient non-community water systems (U.S. Environmental Protection Agency, 1989, p. 608); maximum contaminant levels for pesticides apply to all community water systems (U.S. Environmental Protection Agency, 1989, p. 548); units are micrograms per liter.]

Compound	Maximum contaminant level	Compound	Maximum contaminant level
Purgeable Organic Compounds		Pesticides	
Benzene	5.0	Endrin	0.2
Bromoform	A	Lindane	4.0
Carbon tetrachloride	5.0	Methoxychlor	100
Chloroform	A	Toxaphene	6.0
Dibromochloromethane	A	2,4-D	100
Dichlorobromomethane	A	Silvex (2,4,5-TP)	10
1,4-Dichlorobenzene	75		
1,2-Dichloroethane	5.0		
1,1-Dichloroethylene	7.0		
1,1,1-Trichloroethane	200		
Trichloroethylene	5.0		
Vinyl chloride	2.0		

Purgeable Organic Compounds

The purgeable organic compounds listed in table 1 are not naturally occurring and true background concentrations should be zero; however, they are widely distributed in the environment at trace concentrations because they are used as components in a wide variety of industrial, agricultural, and household products. The purgeable organic compounds considered in this report are carbon tetrachloride, 1,1,1-trichloroethane, trichloroethylene, 1,1-dichloroethylene, benzene, vinyl chloride, 1,4-dichlorobenzene (equivalent to para-dichlorobenzene CAS number 106-46-7), 1,2-dichloroethane, and

total trihalomethanes, which include chloroform, bromoform, dibromochloromethane, and dichlorobromomethane.

During May through September 1989, ground-water samples collected from 72 sites in areas downgradient from the INEL were analyzed for concentrations of purgeable organic compounds (Mann and Knobel, 1990; S.J. Wegner, U.S. Geological Survey, written communication, 1990). The analyses were made by the U.S. Geological Survey's NWQL (National Water Quality Laboratory) using a method equivalent to U.S. Environmental Protection Agency method 524 (Feltz and others, 1985). Concentrations were less than the NWQL reporting level of 0.2 µg/L for all compounds in all Snake River Plain aquifer samples.

During August 1980 Leenheer and Bagby (1982, table 3) collected eight water samples from the Snake River Plain aquifer at sites located on the INEL. The samples were analyzed by the NWQL. Concentrations of all purgeable organic compounds analyzed in all samples were less than 10 µg/L.

In general, background concentrations of the previously named purgeable organic compounds in the Snake River Plain aquifer water are less than 0.2 µg/L. Mann and Knobel (1987, table 2) published data on concentrations of purgeable organic compounds in the Snake River Plain aquifer water for 110 water samples from wells located on or near the INEL. Benzene, carbon tetrachloride, chloroform (which is included in the U.S. Environmental Protection Agency category of total trihalomethanes), 1,1-dichloroethylene, 1,1,1-trichloroethane, and trichloroethylene were present at concentrations larger than the respective reporting levels, usually 0.2 µg/L. INEL site operations have resulted in detectable concentrations of these compounds locally in the Snake River Plain aquifer.

Carbon tetrachloride.--Concentrations of carbon tetrachloride in 18 ground-water samples from the INEL ranged from 0.3 to 6.6 µg/L, with a mean concentration of 2.2 µg/L and a median concentration of 1.8 µg/L. In addition, 87 concentrations were reported as less than 0.2 µg/L, 5 concentrations were reported as less than 3.0 µg/L, and 1 concentration was

reported as less than 20 µg/L. These 93 concentrations were not used in the statistical analysis.

1,1,1-Trichloroethane.--Concentrations of 1,1,1-trichloroethane in 33 ground-water samples from the INEL ranged from 0.2 to 2.6 µg/L, with a mean concentration of 0.6 µg/L and a median of 0.6 µg/L. In addition, 71 concentrations were less than 0.2 µg/L, 5 concentrations were less than 3.0 µg/L, and 1 concentration was less than 20 µg/L; however, these concentrations were not used in the statistical analysis.

Trichloroethylene.--Concentrations of trichloroethylene in 33 ground-water samples from the INEL ranged from 0.2 to 7.7 µg/L, with a mean concentration of 1.5 µg/L and a median of 0.7 µg/L. In addition, 70 concentrations were less than 0.2 µg/L, 5 concentrations were less than 3.0 µg/L, and 1 concentration was 35,000 µg/L; however, these concentrations were not used in the statistical analysis.

1,1-Dichloroethylene.--Two water samples from the Snake River Plain aquifer at the INEL contained 0.2 µg/L of 1,1-dichloroethylene and one contained 49 µg/L. In addition, 102 samples contained less than 0.2 µg/L, and 5 samples contained less than 3.0 µg/L.

Benzene.--One water sample from the Snake River Plain aquifer at the INEL contained 0.3 µg/L of benzene. In addition, 103 samples contained less than 0.2 µg/L, 5 samples contained less than 3.0 µg/L, and 1 sample contained less than 20 µg/L.

Chloroform.--Two water samples from the Snake River Plain aquifer at the INEL contained 0.2 µg/L of chloroform, and three other samples contained 0.4, 0.7, and 1.0 µg/L, respectively. In addition, 99 samples had concentrations less than 0.2 µg/L, 5 had concentrations less than 3.0 µg/L, and 1 had a concentration less than 20 µg/L.

1,4-Dichlorobenzene, 1,2-dichloroethane, vinyl chloride, bromoform, dibromochloromethane, and dichlorobromomethane.--These purgeable organic compounds were not present at concentrations larger than the reporting level in 110 ground-water samples collected at the INEL. Concentrations of 104 samples were less than 0.2 µg/L, 5 samples were less than 3.0 µg/L, and 1 sample was less than 20 µg/L for each of the compounds. Operations at the INEL have not affected concentrations of these compounds in water from the Snake River Plain aquifer beneath the INEL.

Pesticides

True background concentrations of organic compounds used as pesticides should not be present in water in the Snake River Plain aquifer because they are anthropogenic However, they are extensively used by the agricultural industry and have the potential for wide distribution in the environment at trace concentrations. The pesticides considered in this report are the chlorophenoxy acid herbicides 2,4-D and silvex (2,4,5-TP), and the organochlorine insecticides endrin, lindane, methoxychlor, and toxaphene. During May through September 1989, ground-water samples collected from 85 sites in areas upgradient and downgradient from the INEL were analyzed for concentrations of organic pesticides (Edwards and others, 1990; Mann and Knobel, 1990; S.J. Wegner, U.S. Geological Survey, oral communication, 1990).

The analyses for endrin, lindane, methoxychlor, and toxaphene were made by the NWQL using method 0-3104-83 (Wershaw and others, 1987, p. 27-31). In short, the method consists of using hexane for the initial extraction and purifying the extract by adsorption chromatography on an alumina column. If toxaphene was present, an additional purification was conducted using a silica gel column. Concentrations were determined by gas chromatography using an electron-capture detector. The NWQL determined concentrations of 2,4-D and silvex using method 0-3105-83. Briefly, the method consists of chemically extracting the compounds and converting them to their methyl esters. The extract is purified using adsorption chromatography and the methyl ester concentrations are determined by gas chromatography using an

electron-capture detector (Wershaw and others, 1987, p. 40-43). One upgradient sample contained 0.10 µg/L of 2,4-D. All other samples contained concentrations less than the laboratory's reporting level for all compounds. The reporting level for concentrations of pesticide compounds in samples upgradikllHent from the INEL was 0.01 µg/L, except for toxaphene, which was 1.0 µg/L.

Leenheer and Bagby (1982, p. 5) collected four water samples from the Snake River Plain aquifer at sites located on the INEL for pesticide analysis. The samples were collected during August 1980 and analyzed by gas chromatographic procedures. All compounds were reported as less than the reporting level of 0.1 µg/L for toxaphene and 0.01 µg/L for all other compounds (Leenheer and Bagby, 1982, p. 16 and 18).

Comparison of these data indicates that the background concentration for toxaphene in water from the Snake River Plain aquifer is less than 1.0 µg/L, and that for 2,4-D, silvex, endrin, lindane, and methoxychlor, it is less than 0.01 µg/L. Furthermore, it appears that operations at the INEL have not affected pesticide concentrations in water from the Snake River Plain aquifer beneath the INEL.

Selected Inorganic Constituents

Inorganic constituents with established maximum contaminant levels discussed in the following sections are arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, fluoride, and nitrate (U.S. Environmental Protection Agency, 1989, p. 547 and 608). These constituents and their respective maximum contaminant levels are listed in table 2.

Table 2.--Inorganic constituents for which maximum contaminant levels have been established

[The maximum contaminant levels were established pursuant to the recommendations of the U.S. Environmental Protection Agency (1989, p. 547 and 608) for community water systems and are included only for comparison purposes; the maximum contaminant level for nitrate is applicable to both community and noncommunity water systems, excepting the provisions allowed at the discretion of the State (U.S. Environmental Protection Agency, 1989, p. 547, para. d). Units are in micrograms per liter]

Constituent	Maximum contaminant level
Arsenic	50
Barium	1,000
Cadmium	10
Chromium	50
Lead	50
Mercury	2
Selenium	10
Silver	50
Fluoride	4,000
Nitrate	10,000

Arsenic

Arsenic is an ubiquitous element of the upper lithosphere, averaging an estimated 5 g/ton in igneous rocks (Carapella, 1972, p. 41). Concentrations of arsenic were determined in 74 ground-water samples collected during May through September 1989, from areas upgradient and downgradient from the INEL (Edwards and others, 1990; Mann and Knobel, 1990; S.J. Wegner, U.S. Geological Survey, oral communication, 1990). Concentrations ranged from 1 to 5 µg/L, with a mean concentration of 2.5 µg/L and a median concentration of 2 µg/L.

Wood and Low (1988, table 20B) reported concentrations of arsenic for 37 water samples from the Snake River Plain aquifer. Concentrations in 35 samples ranged from 1 to 21 µg/L, with a mean concentration of 3.1 µg/L and

a median concentration of 2 μg/L. In addition, one concentration was reported as less than 1 μg/L and one was reported as 0; these two concentrations were not used in determining the range of concentrations, the mean concentration, or the median concentration.

Arsenic concentrations were reported for 86 water samples collected from wells completed in the Snake River Plain aquifer on or near the INEL (Mann and Knobel, 1988, table 2). Concentrations in 85 samples ranged from 1 to 4 μg/L, with a mean concentration of 1.9 μg/L and a median concentration of 2 μg/L. The arsenic concentration in one sample, reported as less than 1 μg/L, was not used in determining the range of concentrations, the mean concentration, or the median concentration.

Comparison of these data indicates that background concentrations of arsenic in water in the Snake River Plain aquifer are about 2 to 3 μg/L. Furthermore, it appears that operations at the INEL have not affected arsenic concentrations in water in the Snake River Plain aquifer.

Barium

Barium is an ubiquitous trace element in crustal material, averaging 480 ppm barium oxide in igneous rocks and 430 ppm barium oxide in sedimentary rocks (Pilkey 1972, p. 62). During May through September 1989, 74 water samples were collected from areas upgradient and downgradient from the INEL and analyzed for barium concentrations (Edwards and others, 1990; Mann and Knobel, 1990; S.J. Wegner, U.S. Geological Survey, oral communication, 1990). The concentrations ranged from 5 to 140 μg/L with a mean concentration of 54 μg/L and a median concentration of 52.5 μg/L.

Wood and Low (1988, table 20B) reported barium concentrations in 23 water samples from the Snake River Plain aquifer. Concentrations ranged from 20 to 150 μg/L, with a mean concentration of 68 μg/L and a median concentration of 50 μg/L.

Barium concentrations in 86 water samples collected from wells on or near the INEL completed in the Snake River Plain aquifer were reported by Mann and Knobel (1988, table 2). Concentrations ranged from 17 to 190 μg/L, with a mean concentration of 66 μg/L and a median concentration of 56.5 μg/L.

Comparison of these data indicates that background concentrations of barium in water from the Snake River Plain aquifer range from about 50 to about 70 μg/L. Furthermore, operations at the INEL have not affected barium concentrations in water in the aquifer.

Cadmium

Estimates of cadmium abundances in crustal material are as large as 0.5 ppm. In sedimentary shale deposits, the average abundance is 0.3 ppm; in igneous rocks, the average abundance is 0.13 ppm (Fairbridge, 1972, p. 99). During May through September 1989, 74 ground-water samples collected from sites upgradient and downgradient from the INEL were analyzed for cadmium concentrations (Edwards and others, 1990; Mann and Knobel, 1990; S.J. Wegner, U.S. Geological Survey, oral communication, 1990). One sample contained 1 μg/L and another contained 2 μg/L. The 72 remaining samples contained less than 1 μg/L.

Wood and Low (1988, table 20B) reported cadmium concentrations in water from 32 wells completed in the Snake River Plain aquifer. Cadmium concentrations in 2 samples were reported as 1 μg/L, in 1 sample as 3 μg/L, in 2 samples as less than 2 μg/L, and in 27 samples as less than 1 μg/L. Cadmium concentrations in 86 water samples collected from wells on or near the INEL that are completed in the Snake River Plain aquifer were reported as less than 1 μg/L (Mann and Knobel, 1988, table 2).

Comparison of these data indicates that background concentrations of cadmium in water from the Snake River Plain aquifer generally are less than 1 μg/L. Operations at the INEL have had no measurable effect on cadmium concentrations in water in the aquifer.

Chromium

Chromium is introduced into the Earth's crust as a component of basaltic magmas (Smith, 1972, p. 168). Chromium is found in spinels in the olivine-rich inclusions of basaltic rocks (Deer and others, 1967, p. 432).

Ground-water samples collected from May through September 1989 at 74 sites upgradient and downgradient from the INEL were analyzed for dissolved chromium (Edwards and others, 1990; Mann and Knobel, 1990; S.J. Wegner, U.S. Geological Survey, oral communication, 1990). Concentrations in 73 samples ranged from 1 to 50 µg/L, with a mean concentration of 3.4 µg/L and a median concentration of 2 µg/L. The concentration of chromium in one sample, reported as less than 1 µg/L, was not used in determining the range of concentrations, the mean concentration, or the median concentration.

Dissolved chromium concentrations from 86 water samples collected from wells completed in the Snake River Plain aquifer on or near the INEL were reported by Mann and Knobel (1988, table 2). Concentrations in 79 samples ranged from 1 to 280 µg/L, with a mean concentration of 12 µg/L and a median concentration of 7 µg/L. Two concentrations were reported as less than 7 µg/L, two concentrations were reported as less than 5 µg/L, and three concentrations were reported as less than 1 µg/L; these concentrations were not used in determining the range of concentrations, the mean concentration, or the median concentration.

Comparison of these data indicate that background concentrations of dissolved chromium in water from the Snake River Plain aquifer generally range from about 2 to 3 µg/L. Operations at the INEL locally have had a measurable effect on concentrations of dissolved chromium in water in the aquifer.

Lead

Lead is the most abundant heavy element in the Earth's crust, averaging about 15 ppm by weight. Lead commonly substitutes for calcium in plagioclase, amphiboles, and pyroxenes. As a result, the lead-potassium ratio in

basaltic rocks may be relatively large (Wampler, 1972, p. 643-644). Groundwater samples collected from 74 sites upgradient and downgradient from the INEL during May through September 1989 were analyzed for concentrations of lead (Edwards and others, 1990; Mann and Knobel, 1990; S.J. Wegner, U.S. Geological Survey, oral communication, 1990). Concentrations in 29 samples ranged from 1 to 4 µg/L, with a mean concentration of 1.6 µg/L and a median concentration of 1 µg/L. Concentrations in 12 samples were less than 5 µg/L and concentrations in 33 samples were less than 1 µg/L; these concentrations were not used in determining the range of concentrations, the mean concentration, or the median concentration.

Wood and Low (1988, table 20B) reported concentrations of lead in 59 water samples from the Snake River Plain aquifer. Concentrations in 18 samples ranged from 1 to 59 µg/L with a mean concentration of 12 µg/L and a median concentration of 4.5 µg/L. Concentrations in 2 samples were less than 2 µg/L, in 26 samples were less than 10 µg/L, and in 13 samples were reported as 0; these concentrations were not included in determining the range of concentrations, the mean concentration, or the median concentration.

Lead concentrations in 82 of 86 water samples from wells completed in the Snake River Plain aquifer on or near the INEL were less than 5 µg/L (Mann and Knobel, 1988, table 2). One concentration was less than 10 µg/L, one was 6 µg/L, one was 7 µg/L, and one was 9 µg/L.

Comparison of these data indicates that background concentrations of lead in water from the Snake River Plain aquifer generally are less than 5 µg/L. Operations at the INEL have not significantly affected lead concentrations in water in the aquifer.

Mercury

The cosmic abundance of mercury is given by Mason (1966, p. 22) as 0.3 atoms per 10^6 atoms of silica. Estimates of average crustal compositions based on this abundance are as much as 0.077 ppm of mercury. Basalts and

sandstones typically contain up to 0.1 ppm mercury, and limestone can contain as much as 0.048 ppm mercury (Saupé, 1972, p. 705-706). Ground-water samples collected during May through September 1989 from 72 sites in areas upgradient and downgradient from the INEL were analyzed for mercury concentrations (Edwards and others, 1990; Mann and Knobel, 1990; S.J. Wegner, U.S. Geological Survey, oral communication, 1990). Four samples contained 0.1 µg/L, one contained 0.2 µg/L, and one contained 4.7 µg/L. The 66 remaining samples contained less than 0.1 µg/L.

Mercury concentrations from 86 water samples collected from wells on or near the INEL completed in the Snake River Plain aquifer were reported by Mann and Knobel (1988, table 2). Seven samples contained 0.1 µg/L of mercury, three contained 0.2 µg/L, one contained 0.3 µg/L, and one contained 0.4 µg/L. The remaining 74 samples contained less than 0.1 µg/L.

Comparison of these data indicates that background concentrations of mercury in water from the Snake River Plain aquifer generally are less than 0.1 µg/L. Operations at the INEL have not significantly affected mercury concentrations in water in the aquifer.

Selenium

Crustal concentrations of selenium range from 0.05 to 0.14 ppm and it is relatively evenly distributed in silicic and mafic rocks (Rapp, 1972, p. 1,080). Ground-water samples collected during May through September 1989 from 74 sites in areas upgradient and downgradient from the INEL were analyzed for selenium concentrations (Edwards and others, 1990; Mann and Knobel, 1990; S.J. Wegner, U.S. Geological Survey, oral communication, 1990). Concentrations in 19 samples ranged from 1 to 2 µg/L, with a mean concentration of 1.0 µg/L and a median concentration of 1 µg/L. In addition, 55 samples had concentrations less than 1 µg/L; however, these concentrations were not used in determining the range of concentrations, the mean concentration, or the median concentration.

Selenium concentrations for 86 water samples collected from Snake River Plain aquifer wells located on or near the INEL were reported by Mann and Knobel (1988, table 2). Concentrations in 79 samples ranged from 1 to 5 µg/L, with a mean concentration of 1.1 µg/L and a median concentration of 1 µg/L. In addition, seven concentrations were reported as less than 1 µg/L; however, these concentrations were not used in determining the range of concentrations, the mean concentration, or the median concentration.

Comparison of these data indicates that the background concentration of selenium in water from the Snake River Plain aquifer generally is less than 1 µg/L. Operations at the INEL locally may have had a slight effect on selenium concentrations in water in the aquifer.

Silver

The concentration of silver is about 0.2 ppm in average crustal rocks (Cloke, 1972, p. 1,092). Ground-water samples collected during May through September 1989 from 74 sites in areas upgradient and downgradient from the INEL were analyzed for silver concentrations (Edwards and others, 1990; Mann and Knobel, 1990; S.J. Wegner, U.S. Geological Survey, oral communication, 1990). Concentrations in 19 samples ranged from 1 to 2 µg/L, with a mean concentration of 1 µg/L and a median of 1 µg/L. In addition, 55 samples with reported concentrations less than 1 µg/L were not used in determining the range of concentrations, the mean concentration, or the median concentration.

Silver concentrations from 86 water samples collected from Snake River Plain aquifer wells located on or near the INEL were reported by Mann and Knobel (1988, table 2). Concentrations in nine samples ranged from 1 to 2 µg/L, with a mean concentration of 1 µg/L and a median of 1 µg/L. In addition, 77 concentrations were reported as less than 1 µg/L; these concentrations, however, were not used in determining the range of concentrations, the mean concentration, or the median concentration.

Comparison of these data indicates that the background concentration of silver in water from the Snake River Plain aquifer generally is less than 1 µg/L. Operations at the INEL probably have not affected silver concentrations in water in the aquifer.

Fluoride

Fluoride, the ionic form of fluorine, is widely distributed in the lithosphere and hydrosphere. It is present in nearly all igneous rocks where it substitutes for the hydroxyl ion in the mineral lattices of apatite, micas, and amphiboles. In sedimentary rocks, it occurs primarily in detrital apatite. Fluoride has been used as a flux in industrial processes for more than two centuries and recently has been added to drinking water supplies as a means of reducing dental caries (Simpson, 1972, p. 377-378). As a result, the potential exists for fluoride to be widely distributed in the environment.

Wood and Low (1988, table 20A) reported concentrations of fluoride for 135 water samples from the Snake River Plain aquifer. Concentrations ranged from 0.1 to 4.0 mg/L, with a mean concentration of 0.5 mg/L and a median concentration of 0.4 mg/L.

Water samples collected during 1989 from 23 wells and springs on and near the INEL were analyzed for fluoride concentrations. The concentrations ranged from 0.1 to 1.0 mg/L, with a mean concentration of 0.3 mg/L and a median concentration of 0.2 mg/L.

Comparison of these data indicates that background concentrations of fluoride in water in the Snake River Plain aquifer generally range from about 0.4 to 0.5 mg/L. Operations at the INEL probably have not affected fluoride concentrations in water in the aquifer.

Nitrate

Nitrate concentrations in ground water are most commonly from anthropogenic sources, including chemical fertilizers, barnyard wastes, and septic tank drainage. The maximum contaminant level for nitrate as nitrogen is 10 mg/L (table 2).

Nitrate concentrations as nitrogen were determined in water samples collected from 92 wells completed in the Snake River Plain aquifer (Wood and Low, 1988, table 20A). Concentrations ranged from 0 to 4.7 mg/L, and were distributed about a mean concentration of 1.29 mg/L and a median concentration of 0.98 mg/L (fig. 17). Water samples were collected in May 1989 from 12 wells and 3 irrigation wastewater drains about 65 mi southwest of the INEL (Mann and Knobel, 1990). Nitrate concentrations in these samples ranged from 0.94 to 5.00 mg/L, with a mean concentration of 1.86 mg/L and a median concentration of 1.35 mg/L.

Water samples collected in October 1988 from 43 wells at the INEL were analyzed for nitrate. Concentrations, expressed as nitrogen, ranged from 0.1 to 5.5 mg/L, and were distributed about a mean concentration of 1.90 mg/L and a median concentration of 1.40 mg/L (fig. 17). Background nitrate concentrations in water in the Snake River Plain aquifer generally range from 0 to about 1.4 mg/L.

SUMMARY

Radionuclides and chemical constituents in ground water in the vicinity of the INEL include both naturally occurring and anthropogenic constituents originating from nuclear weapons tests and other widespread sources. Background concentrations of these constituents were determined from chemical analyses of ground-water samples collected from wells at the INEL, the Snake River Plain, and throughout the State of Idaho.

The range, mean, and median of concentrations for respective constituents provided an indication of the distribution of these constituents in

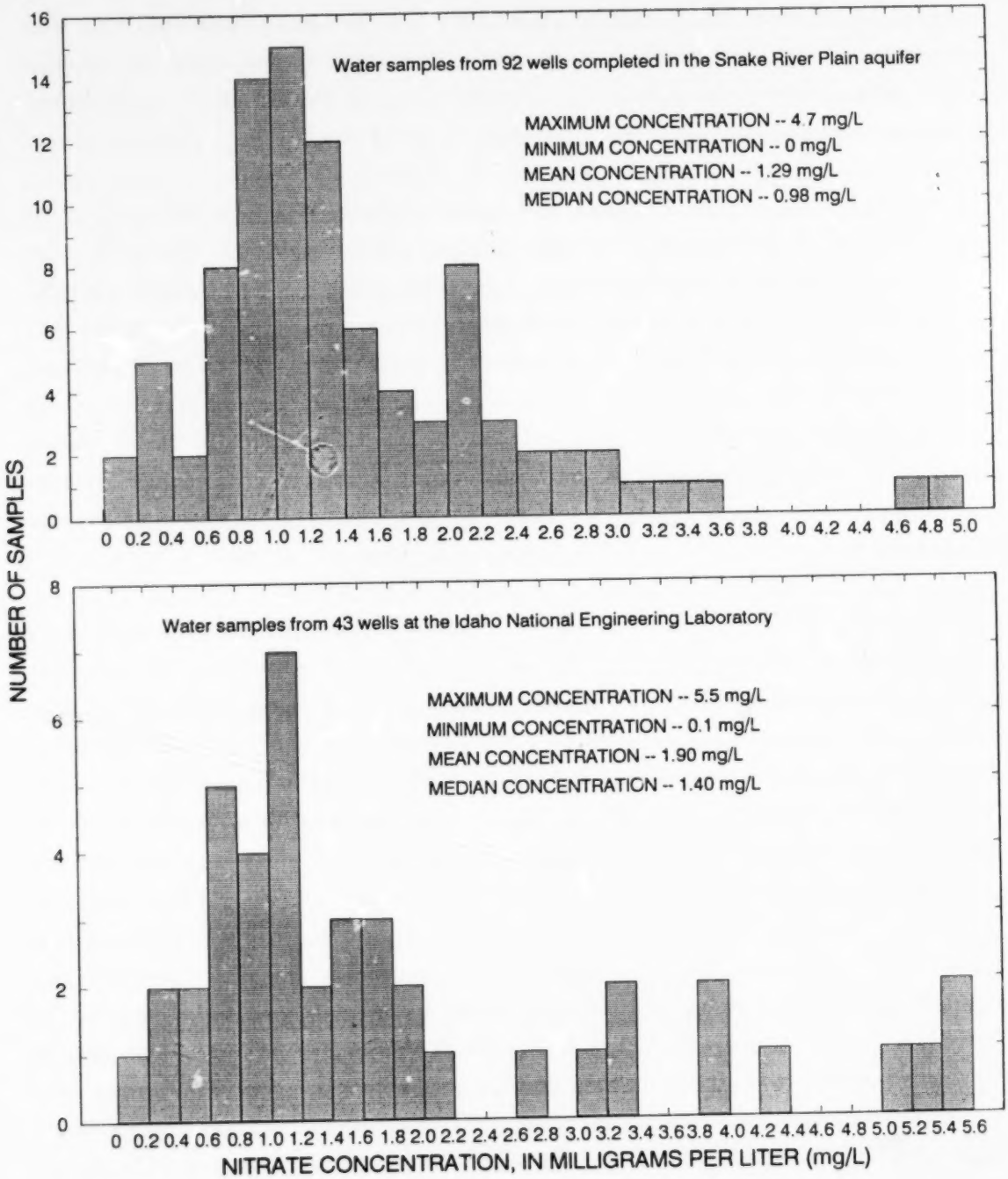
Water samples from 92 wells completed in the Snake River Plain aquifer
MAXIMUM CONCENTRATION -- 4.7 mg/L
MINIMUM CONCENTRATION -- 0 mg/L
MEAN CONCENTRATION -- 1.29 mg/L
MEDIAN CONCENTRATION -- 0.98 mg/L
Water samples from 43 wells at the Idaho National Engineering Laboratory
MAXIMUM CONCENTRATION -- 5.5 mg/L
MINIMUM CONCENTRATION -- 0.1 mg/L
MEAN CONCENTRATION -- 1.90 mg/L
MEDIAN CONCENTRATION -- 1.40 mg/L
NUMBER OF SAMPLES
NITRATE CONCENTRATION, IN MILLIGRAMS PER LITER (mg/L)

Figure 17.--The distribution of nitrate concentrations in water samples from the Snake River Plain aquifer.

water. Radionuclide, organic compound, and inorganic chemical data sets were selected because of their geographic distribution and because results were obtained using recent analytical methods using sensitive instrumentation.

Background concentrations for total uranium in ground water in Idaho range from 0 to about 9 pCi/L. Background concentrations for ^{226}Ra and ^{228}Ra in ground water in Idaho range from 0 to about 0.1 and 0 to 0.3 pCi/L, respectively. Dissolved ^{222}Rn concentrations can vary widely. Background concentrations for dissolved ^{222}Rn probably range from 0 to about 250 pCi/L.

Detectable background concentrations of the transuranic elements should not be present in water from the Snake River Plain aquifer. Operations at the INEL locally have affected background concentrations of some transuranic elements.

Background concentrations of ^{3}H in ground water in Idaho generally range from 75 to 150 pCi/L. Wastewater-disposal practices at the INEL locally have increased the ^{3}H concentration in water from the Snake River Plain aquifer. Concentrations of ^{90}Sr in water from the aquifer generally are zero. Operations at the INEL locally have affected concentrations of ^{90}Sr in water from the aquifer. Background concentrations of ^{129}I in the Snake River Plain aquifer range from 0 to 0.05 pCi/L. Facility operations at the INEL locally have affected ^{129}I concentrations in water from the aquifer.

Background concentrations for gross alpha-particle radioactivity in ground water in Idaho generally range from 0 to about 5 pCi/L. Background concentrations for gross beta-particle radioactivity generally range from zero to about 8 pCi/L. Gamma-emitting radionuclides identified using gamma spectrometry include ^{137}Cs, ^{60}Co, and ^{40}K. Because ^{137}Cs and ^{60}Co do not occur naturally, concentrations in water from the Snake River Plain aquifer generally are zero. Background concentrations of ^{40}K are estimated from the relative abundance with respect to total potassium to be about 300 pCi/L. Concentrations in water from a limited number of sites at the INEL were less than the reporting level.

Background concentrations of selected organic compounds, including carbon tetrachloride, 1,1,1-trichloroethane, trichloroethylene, 1,1-dichloroethylene, benzene, chloroform, 1,4-dichlorobenzene, 1,2-dichloroethane, vinyl chloride, bromoform, dibromochloromethane, and dichlorobromomethane should not be present in water from the Snake River Plain aquifer because they are anthropogenic compounds. Operations at the INEL probably have affected concentrations of carbon tetrachloride, 1,1,1-trichloroethane, trichloroethylene, 1,1-dichloroethylene, and chloroform, in water in the aquifer. Operations at the INEL have had no effect on concentrations of vinyl chloride, 1,4-dichlorobenzene, 1,2-dichloroethane, bromoform, dibromochloromethane, and dichlorobromomethane.

The background concentration for toxaphene in water from the Snake River Plain aquifer is less than 1.0 µg/L, and background concentrations of 2,4-D, silvex, endrin, lindane, and methoxychlor are less than 0.01 µg/L. Operations at the INEL have not affected pesticide concentrations in Snake River Plain aquifer water.

Background concentrations of arsenic in water from the Snake River Plain aquifer are about 2 to 3 µg/L. Concentrations of barium range from about 50 to about 70 µg/L. Concentrations of cadmium in ground water on or near the INEL are less than 1 µg/L. Concentrations of dissolved chromium generally are about 2 to 3 µg/L. Concentrations of lead and mercury generally are less than 5 µg/L and 0.1 µg/L, respectively. Concentrations of selenium and silver generally are less than 1 µg/L. Operations at the INEL have not affected concentrations of arsenic, barium, cadmium, mercury, and silver in water from the aquifer but probably have had a slight effect on concentrations of dissolved chromium, lead, and selenium.

Background concentrations of fluoride in water from the Snake River Plain aquifer range from about 0.4 to 0.5 mg/L. Operations at the INEL probably have not affected fluoride concentrations. Background concentrations of nitrate as nitrogen in water from the aquifer generally range from 0 to about 1.4 mg/L.

SELECTED REFERENCES

Carapella, S.C., Jr., 1972, Arsenic: element and geochemistry, in Fairbridge, R.W., ed., The encyclopedia of geochemistry and environmental sciences: Stroudsburg, Pa, Dowden, Hutchinson, and Ross, p. 41-42.

Cloke, P.L., 1972, Silver: element and geochemistry, in Fairbridge, R.W., ed., The encyclopedia of geochemistry and environmental sciences: Stroudsburg, Pa, Dowden, Hutchinson, and Ross, p. 1,092-1,093.

Deer, W.A., Howie, R.A., and Zussman, J., 1967, An introduction to the rock-forming minerals: London, Longmans, Green and Co., 528 p.

Durrance, E.M., 1986, Radioactivity in geology: principles and applications: New York, N.Y., John Wiley and Sons, Inc., 441 p.

Edwards, D.D., Bartholomay, R.C., and Bennett, C.M., 1990, Nutrients, pesticides, surfactants, and trace metals in ground water from the Howe and Mud Lake areas upgradient from the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Open-File Report 90-565, 18 p.

Eisenbud, 1973, Environmental radioactivity (2nd ed.): New York, Academic Press, 542 p.

Fairbridge, R.W., 1972, Cadmium: element and geochemistry, in Fairbridge, R.W., ed., The encyclopedia of geochemistry and environmental sciences: Stroudsburg, Pa, Dowden, Hutchinson, and Ross, p. 99-100.

Feltz, H.R., Duncan, S.S., and Zepp, Ann, eds., 1985, 1986-87-88 National Water Quality Laboratory Services Catalog: U.S. Geological Survey Open-File Report 86-232, unnumbered.

Gilbert, R.O. and Kinnison, R.R., 1981, Statistical methods for estimating the mean and variance from radionuclide data sets containing negative, unreported, or less-than values: Health Physics v. 40 (March), Pergamon Press, Ltd., p. 377-390.

Harenberg, W.A., Jones, M.L., O'Dell, Ivalou, and Cordes, S.C., 1988, Water resources data, Idaho, water year 1988: U.S. Geological Survey Water-Data Report ID-88-1, 669 p.

Hoff, D.L., Mitchell, R.G., Bowman, G.C., and Moore, Richard, 1990, The Idaho National Engineering Laboratory site environmental report for calendar year 1989: Environmental Sciences Branch, Radiological and Environmental Sciences Laboratory, Idaho Operations Office, U.S. Department of Energy Report DOE/ID-12082(89), 45 p.

Horton, T.R., 1985, Nationwide occurrence of radon and other natural radioactivity in public water supplies: U.S. Environmental Protection Agency Report EPA 520/5-85-008, 1985, 208 p.

Iman, R.L. and Conover, W.J., 1983, A modern approach to statistics: John Wiley & Sons, Inc., 497 p.

Kaufman, Aaron, 1972, Radioactivity in rocks, in Fairbridge, R.W., ed., The encyclopedia of geochemistry and environmental sciences: Stroudsburg, Pa, Dowden, Hutchinson, and Ross, p. 991-995.

Knobel, L.L., and Mann, L.J., 1988, Radionuclides in ground water at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Open-File Report 88-731 (DOE/ID-22077), 37 p.

Kretz, Ralph, 1972, Potassium: element and geochemistry, in Fairbridge, R.W., ed., The encyclopedia of geochemistry and environmental sciences: Stroudsburg, Pa, Dowden, Hutchinson, and Ross, p. 970-971.

Leenheer, J.A., and Bagby, J.C., 1982, Organic solutes in ground water at the Idaho National Engineering Laboratory: U.S. Geological Survey Water-Resources Investigations Report 82-15 (IDO-22061), 39 p.

Mann, L.J., 1989, Tritium concentrations in flow from selected springs that discharge to the Snake River, Twin Falls-Hagerman area, Idaho: U.S. Geological Survey Water Resources Investigations Report 89-4156 (DOE/ID-22084), 20 p.

Mann, L.J., Chew, E.W., Morton, J.S., and Randolph, R.B., 1988, Iodine-129 in the Snake River Plain aquifer at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 88-4165 (DOE/ID-22076), 27 p.

Mann, L.J., and Knobel, L.L., 1987, Purgeable organic compounds in ground water at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Open-File Report 87-766 (DOE/ID-22074), 23 p.

----- 1988, Concentrations of nine trace metals in ground water at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Open-File Report 88-332 (DOE/ID-22075), 17 p.

----- 1990, Radionuclides, metals, and organic compounds in water, eastern part of A&B Irrigation District, Minidoka County, Idaho: U.S. Geological Survey Open-File Report 90-191 (DOE/ID-22087), 36 p.

Mason, Brian, 1966, Principles of geochemistry: New York, John Wiley, 329 p.

Michel, R.L., 1989, Tritium deposition in the continental United States, 1953-83: U.S. Geological Survey Water-Resources Investigations Report 89-4072, 46 p.

National Council on Radiation Protection and Measurements, 1979, Tritium in the environment: National Council on Radiation Protection and Measurements, Report no. 62, 125 p.

Pilkey, Orrin, 1972, Barium: element and geochemistry, in Fairbridge, R.W., ed., The encyclopedia of geochemistry and environmental sciences: Stroudsburg, Pa, Dowden, Hutchinson, and Ross, p. 62-63.

Pittman, J.R., Jensen, R.G., and Fischer, P.R., 1988, Hydrologic conditions at the Idaho National Engineering Laboratory, 1982 to 1985: U.S. Geological Survey Water-Resources Investigations Report 89-4008 (DOE/ID-22078), 73 p.

Rapp, George, Jr., 1972, Selenium: element and geochemistry, in Fairbridge, R.W., ed., The encyclopedia of geochemistry and environmental sciences: Stroudsburg, Pa, Dowden, Hutchinson, and Ross, p. 1,079-1,080.

Saupé, F.R., 1972, Mercury: element and geochemistry, in Fairbridge, R.W., ed., The encyclopedia of geochemistry and environmental sciences: Stroudsburg, Pa, Dowden, Hutchinson, and Ross, p. 704-708.

Simpson, D.R., 1972, Fluorine: element and geochemistry, in Fairbridge, R.W., ed., The encyclopedia of geochemistry and environmental sciences: Stroudsburg, Pa, Dowden, Hutchinson, and Ross, p. 377-378.

Smith, C.H., 1972, Chromium: element and geochemistry, in Fairbridge, R.W., ed., The encyclopedia of geochemistry and environmental sciences: Stroudsburg, Pa, Dowden, Hutchinson, and Ross, p. 167-170.

U.S. Environmental Protection Agency, 1989, Protection of environment: Code of Federal Regulations 40: Office of the Federal Register, National Archives and Records Administration, Parts 100 to 149, 948 p.

Wampler, J.M., 1972, Lead: element and geochemistry, in Fairbridge, R.W., ed., The encyclopedia of geochemistry and environmental sciences: Stroudsburg, Pa, Dowden, Hutchinson, and Ross, p. 642-644.

Wegner, S.J., 1989, Selected quality assurance data for water samples collected by the U.S. Geological Survey, Idaho National Engineering Laboratory, Idaho, 1980 to 1988: U.S. Geological Survey Water Resources Investigations Report 89-4168 (DOE/ID-22085), 91 p.

Wershaw, R.L., Fishman, M.J., Grabbe, R.R., and Lowe, L.E., 1987, Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chap. A3, 80 p.

Wood, W.W., and Low, W.H., 1988, Solute geochemistry of the Snake River Plain regional aquifer system, Idaho and eastern Oregon: U.S. Geological Survey Professional Paper 1408-D, 79 p.